The Blast Furnace and Steel Plant

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The Blast Furnace and Steel Plant

Vol. X PITTSBURGH, PA., AUGUST, 1922 No. 8

Heat Transmission in the Hot-Galvanizing Process

Describing the Temperature Distribution of the Process—Rate of Motion of the Sheets Through the Bath Should Vary With the Sheet Thickness If Based on the Factor of Heat Transmission.

By J. D. KELLER

PART II

FOR the purpose of mathematical investigation, the zinc bath may be considered as a heat-conducting medium of indefinitely large extent, originally at a constant temperature throughout. This assumption is permissible in view of the fact that the extent of the liquid is indeed very large in comparison with the thickness of the steel sheet (dimensions about 40 in. and 0.02 in. respectively), and that heat is continually added as required to keep the bath temperature constant.

The inter-relation of temperature, space and time in an infinite medium is expressed by a form of mathematical function which is practically identical with the Gauss probability-of-error integral — sometimes called simply the "Gauss integral" or "probability integral"—or by a combination of such functions. To get the meaning of this form of integral clearly in mind, consider first that in an infinite, homogeneous medium, originally at zero temperature throughout, a finite quantity of heat is developed at a given instant in one certain infinitesimally thin layer of the medium, see Fig. 3 (called an "instantaneous plane source").

The expression for flow of heat from this layer throughout the remainder of the medium must, of course, satisfy the fundamental Fourier equation

$$a^2 \frac{d^2T}{dx^2} = \frac{dT}{dt} \qquad \ldots\ldots\ldots\ldots(2$$

and the corresponding equation * connecting temperature with time and space is

$$T = \frac{C_1}{\sqrt{\pi}} \cdot \frac{1}{\sqrt{4a^2t}} \cdot e^{-\frac{x^2}{4a^2t}} \qquad \ldots\ldots\ldots\ldots(3$$

T being the temperature at distance **x** from the layer, after time **t** has elapsed from the beginning of the heat flow. **e** is the number 2.718—, the base of Napierian logarithms. The factor a^2 is a constant, called the "diffusivity," which depends upon the properties of the material. It is equal to conductivity λ divided by the product of specific heat **c** times density **w**; or $a^2 = \frac{\lambda}{w.c}$. C_1 is a constant determined by the quantity of heat developed.

If, instead of being confined to an infinitesimally thin layer, the heat is distributed initially in some arbitrary mode through a section of the medium of finite thickness, then the temperature equation may be arrived at by considering the initial temperature-space curve as built up of a series of curves of contiguous infinitesimal layers (see Fig. 4), and similarly the temperature-space curve for any subsequent time is built up of the sum of the superimposed curves of the individual layers. If the initial temperature distribution can be expressed as a function of the space position, or $T_0 = F(E)$, then the temperature distribution for any subsequent time **t** is given by the summation

$$T = \frac{1}{\sqrt{\pi}} \cdot \frac{1}{\sqrt{4a^2t}} \int_{-\infty}^{+\infty} F(E) \cdot e^{\frac{-(E-x)^2}{4a^2t}} . dE \qquad \ldots\ldots\ldots\ldots(4$$

This can be simplified by substituting

$$\beta = \frac{E-x}{2a\sqrt{t}}, \text{ or } E = x + 2a\sqrt{t} \cdot \beta$$

which gives

$$T = \frac{1}{\sqrt{\pi}} \int_{-\infty}^{+\infty} F(x + 2a\sqrt{t} \cdot \beta) \cdot e^{-\beta^2} \, d\beta \ldots\ldots(5$$

If the initial temperature is constant, independent of **x**, as in the present case, then $F(x + 2a\sqrt{t} \cdot \beta) = C$ and

---

*Grober, Grundgesetze der Warmeleitung.

$$T_x = C \, . \, \frac{2}{\sqrt{\pi}} \int_0^z e^{-B^2} \, . \, d\beta$$

The last part of this expression is simply the probability integral, which will in what follows be written G(z), meaning the expression

$$\frac{2}{\sqrt{\pi}} \int_{\beta=0}^{\beta=B^2} e \, . \, d\beta.$$

The values of this integral, for various values of the argument **z**, may be found in treatises on theory of probabilities.

If the heat conducting medium is of the same homogeneous material throughout, as for instance in the case of a slab of hot steel inserted into a space between the parallel ends of two long steel shafts at zero temperature, then the problem can be solved † without great difficulty by splitting the integral into three parts, thus:

$$T = \frac{1}{\sqrt{\pi}} \int_{-\infty}^{a} o \, . \, e^{-\beta^2} \, . \, d\beta + \frac{1}{\sqrt{\pi}} \int_{a}^{b} T_o \, . \, e^{-\beta^2} \, . \, d\beta + \frac{1}{\sqrt{\pi}} \, . \int_{b}^{+\infty} o \, . \, e^{-\beta^2} \, . \, d\beta, \text{ or } T = \frac{T_o}{\sqrt{\pi}} \int_{a}^{\beta} e^{-\beta^2} \, . \, d\beta$$

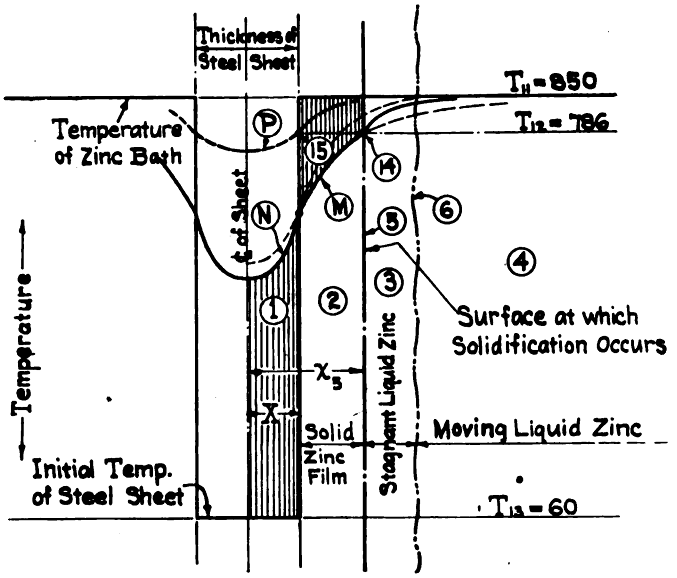

Fig. 2—Conditions during galvanizing.

For each particular evaluation of the integral, **x** and **t** are constant, and **E** is the variable of integration. This means that the limits **a** and **b** must be the values of β corresponding to $E = -X$ and $E = +X$. Substituting in the definitive equation $\beta = \frac{E - x}{2a\sqrt{t}}$ gives $a = \frac{-X - x}{2a\sqrt{t}}$ and $a = \frac{+X - x}{2a\sqrt{t}}$. The temperature-space-time equation is

$$T = \frac{T_o}{\sqrt{\pi}} \left[\int_{\beta=o}^{\beta=\left(\frac{X-x}{2a\sqrt{t}}\right)} e^{-\beta^2} \, . \, d\beta - \int_{\beta=o}^{\beta=\left(\frac{-X-x}{2a\sqrt{t}}\right)} e^{-\beta^2} \, . \, d\beta \right] \text{..........(6}$$

Corresponding curves are shown in Fig. 4.

While this solution, applying to a homogeneous medium, is fairly simple, matters become much more complicated when a medium composed of layers of different materials must be dealt with. In the galvanizing process, each of the four layers shown in Fig. 2 has its own special diffusivity a^2 and conductivity λ, different from those of the other layers. An additional complicating factor, of great importance, is the transformation of latent heat into sensible heat, and vice versa, at the "freezing" or melting boundary plane (indicated by [5] in Fig. 2), as the layer (2) thickens or shrinks. The temperature equation could not be expressed by one Gauss integral alone, but would have to be built up of a combination of such integrals. The extreme mathematical complications have prevented a solution being reached. A problem resembling the present one in some respects—that of determining the penetration of the frost boundary into moist earth—was solved by Neumann,* but in the solution only two layers or sections of different substances were dealt with, and the temperature of one surface was considered as being held constant at all times. No such simplifications can be introduced in the present case.

Without attempting a rigorous mathematical solution expressing the time-space-temperature variation, it is possible by considering the extreme or limiting conditions to arrive at quite definite results as respects time requirement for heating, and temperature inequalities inside the steel sheet.

In Neumann's solution, referred to above, it was found that the distance of penetration of the frost-boundary is proportional to the square root of the elapsed time, this apparently holding true regardless of the relation between conductivity, latent heat, and specific heats of the different materials. It will be of interest to study first whether any such relation can be deduced in the present case, between time and distance through which the solidification or melting surface—(5) in Fig. 3—has moved from its starting plane. As this surface must maintain a constant temperature—that of melting zinc—its motion might be expected to coincide with that of a constant temperature plane expressed by some equation of unknown constants but of the general form of eq. (3 or (6. Considering first, for simplicity, eq. (3, and denoting any constant temperature T by C_2, the operations of transposition and squaring give

$$\left(\frac{C_2}{C_1}\right)^2 . \, \pi \, . \, 4a^2t = e^{\frac{-2x^2}{4a^2t}}$$

---

†Ingersoll and Zobel, Mathematical Theory of Heat Conduction, p. 70.

*See Riemann-Weber, Partielle Diff. Gleich.

Taking logarithms of both sides, to base **e**, gives

$$\log_e \left(\frac{C_2}{C_1}\right)^2 . \pi . 4a^2t = -\frac{x^2}{2a^2t}$$

Writing instead of $\left(\frac{C_2}{C_1}\right)^2 . \pi . 4a^2$, the expression $\frac{C_3}{e}$, gives

$$x = \sqrt{-2a^2t . \log \left(\frac{C_3t}{e}\right)}$$

$$\text{or } x = \sqrt{-C_4t . \log \left(\frac{C_3t}{e}\right)} \dots\dots\dots\dots (7$$

A brief study of this expression shows that the distance **x** of the constant temperature plane from its starting point increases rapidly at first, reaches a maximum when $t = \frac{1}{C_3}$, then begins to decrease. The motion of one such constant-temperature plane is indicated in Fig. 3 by the series of points 1, 2, 3, 4, 5. At time $t = \frac{e}{C_3}$, the plane has come back to its starting point.

Extending the investigation to the case of a layer of finite thickness, equation (6, the expression for the motion of the constant-temperature plane is found to be very similar to that of the preceding case. It has, however, an additional term which takes care of the fact that the motion now starts, not at the origin, but at the surfaces of contact of the finite with the infinite sections. The equation for this case is

$$x = \sqrt{X^2 - 2a^2t . \log_e \left[\left(\frac{T}{T_0 . 4X}\right)^2 . \pi . 4a^2t\right]} \text{ or}$$

$$x = \sqrt{X^2 - C_4t . \log \left(\frac{C_5 . t}{e}\right)} \dots\dots\dots\dots (8$$

in which **x** is the distance of the constant-temperature plane from the origin, taken at the center of the finite section; **X** is half the thickness of that section; C_4 and C_5 are constants depending upon the initial temperature T_0, the constant temperature **T** and the thermal properties of the material; and the other symbols have the same meaning as above. The form of curve corresponding to equation (8 is shown by the broken line (D) in Fig. 5.

This equation expresses the motion of a constant-temperature plane in a medium which is homogeneous throughout and is free from latent heat or heat-of-fusion effects. Whether it will apply in the more complicated case under consideration depends at least in part upon the boundary conditions. Referring to Fig. 2, temperature T_{12} is constant and equal to the melting point of zinc, 786 deg. F. * T_{11} is also constant, or at any rate its variation is negligibly small, because heat transmission occurs with extreme rapidity in the violently agitated zinc bath (4). Finally, there is no reason why the resistance of film (3) should vary, if rate of motion of the sheet through the bath is constant. The conclusion from these considerations is that the rate of heat transmission must also be constant. Heat is transferred from the bath (4) through film (3) at an unvarying rate, entirely independent of the rate at which heat is being taken up by the steel sheet. The film of zinc acts in effect as a heat-reservoir, first giving out and later absorbing heat as required to make up the difference between rate of supply from the bath and rate of absorption by the sheet. At the first contact, the sheet is taking up heat at an enormous rate, and the zinc must solidify quickly in order to evolve the make-up heat. Later, the sheet absorbs heat less quickly than it is supplied, and the melting of the zinc takes up the excess. Mathematically expressed, this takes the form of the equation

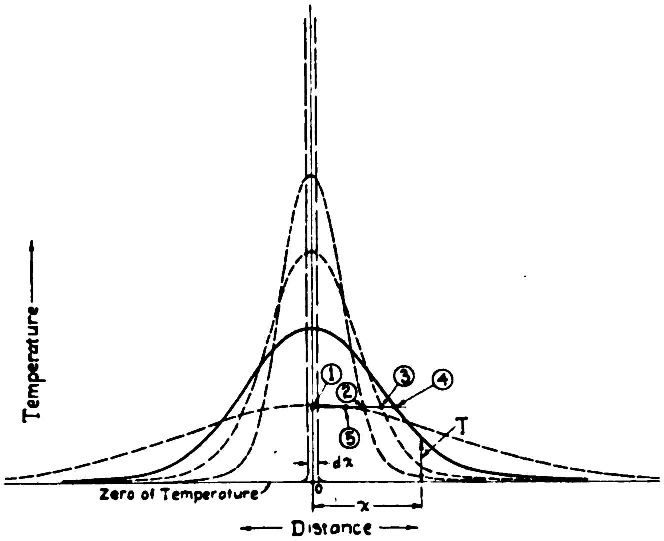

Fig. 3—Flow of heat from an infinitesimal layer.

$$W_2 . Q . \frac{dx}{dt} = \lambda_2 . \frac{dT_2}{dx} - k . (T_{11} - T_{12}) \dots (9$$

applying to the boundary surface (5), Fig. 2 . w_2 is the density of the zinc, **Q** its heat of fusion, and λ_2 its conductivity; **k** is the coefficient of heat transmission through film (3).

As stated above, the relative effect of the various factors can be brought out most clearly by carrying conditions to extremes. First, suppose that heat of fusion is finite, specific heat is finite, but that the conductivities of the steel sheet and of the solid zinc film are indefinitely large, in comparison with the rate of heat input. Then the temperatures would equalize almost instantaneously in the interior of the sheet and in the zinc film; the surface (5) would move outward with practically infinite velocity to its maximum distance, after which the film (2) would melt off at a uniform rate. This is indicated by the dot-dash curve (F) in Fig. 5.

The maximum thickness x_5 of the solid film, represented by the point (A) in that figure, can be determined from the consideration that (under these particular conditions) all of the heat absorbed by the steel sheet must come from the solidification and cooling of the zinc film (2), or

---

***If the zinc bath has become contaminated by absorbing much iron, the fusion temperature is higher.**

$$w_1 \cdot c_1 \cdot X \cdot (T_{12} - T_{13}) = (x_5 - X) \cdot w_2 \cdot [Q + C_2 \cdot (T_{11} - T_{12})].$$

Substitution of numerical values gives

$$\text{limit } [\frac{(x_5 - X)}{2X}] = \frac{488 \times 0.133 \times (786 - 60)}{2 \times 430 \times [0.105 \times (850 - 786) + 50]} = 0.965$$

The thickness of the solid zinc film on either side could never exceed 96½ per cent of the thickness of the steel sheet. Actually it must be considerably less than that, first, because the conductivity is not infinite, and not quite so much heat is absorbed by the steel as would be the case if its temperature rose at once throughout to that of melting zinc; second, because film (2) does not attain its maximum thickness instantly, but requires a finite time interval, during which heat flows in through surface (5), so that less heat need be furnished by solidification of zinc.

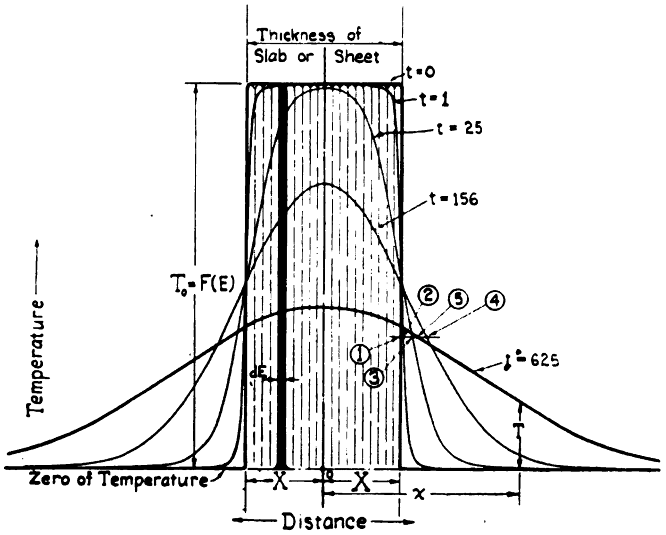

Fig. 4—Flow of heat from a slab of finite thickness.

At the other extreme, suppose that conductivity and specific heat are finite, but heat of fusion is zero. Then the curve of motion of the surface (5) would be of the form expressed by equation (8 and shown by the broken line (D) in Fig. 5.

The true curve of motion will evidently have a form intermediate between the two, and nearer to the one or the other as the influence of conductivity or of heat-of-fusion varies in comparison to rate of heat input. The solid line (E) of Fig. 5 represents one such curve.

Considering again equation (9 as applied to the conditions of the first limiting curve, (F) of Fig. 5, it is evident that as the second term drops out—the steel sheet in this case being at uniform temperature throughout and absorbing no heat after the peak (A) of the motion curve is passed—the slope of curve (F) would be

$$\frac{dx}{dt} = \frac{-K \cdot (T_{11} - T_{12})}{W_2 \cdot Q} = \text{constant.}$$

The slope of curve (P) in Fig. 2, when the solid film has just disappeared, would of course be

$$\frac{dT_1}{dx} = \frac{dT_2}{dx} = \text{zero.}$$

As applied to the second limiting curve (D) in Fig. 5, the first term of equation (9 disappears ($Q =$ zero) and this would give

$$\frac{dT_2}{dx} = \frac{k \cdot (T_{11} - T_{12})}{\lambda_2}.$$

At point (15) in Fig. 2, $\lambda_2 \frac{dT_2}{dx} = \lambda_1 \frac{dT_1}{dx}$, hence $\frac{dT_1}{dx}$ would equal $\frac{k \cdot (T_{11} - T_{12})}{\lambda_1}$.

In the actual case, to which some motion curve of the form of (E) in Fig. 5 applies, the value of $\frac{dT_1}{dx}$ will lie somewhere between these limits. That is to say, the slope of the temperature-space curve at the surface of the steel sheet and at the instant when the solid zinc film has just disappeared (point [15] in Fig. 2) be greater than zero and less than

$$\frac{dT_1}{dx} = \frac{k \cdot (T_{11} - T_{12})}{\lambda_1} \quad \ldots\ldots\ldots\ldots(10$$

This furnishes a means of finding the limiting temperature difference inside the steel sheet. As stated above, the equation of curves (M), (N) and (P) of Fig. 2 are Gauss integrals; however, the constants are unknown. Curve (P) for any one time may be expressed thus:

$$T_1 = \tfrac{1}{2} A_1 \cdot G\,[B_1 \cdot (X - x)] - \tfrac{1}{2} A_1 \cdot G\,[B_1 \cdot (-X - x)] \quad \ldots\ldots\ldots\ldots(11$$

Differentiation gives the slope as

$$\frac{dT_1}{dx} = \tfrac{1}{2} A_1\, B_1 \cdot \frac{2}{\sqrt{\pi}} [e^{-B_1^2 \cdot (X - x)^2} - e^{-B_1^2 (-X - x)^2}] \quad ..(12$$

By equating (10 and (12 and substituting numerical values, the constants A_1 and B_1 may be determined. Of course they apply only for one fixed time, and equation (11 can only express the variation of temperature with space, and not with time. Substituting the constants thus found in (11, the limiting values of temperature T_1 may be found at $x = 0$, the center of the sheet.

It should be understood that the temperature toward which all parts of the system are approaching—in this case the temperature of the zinc bath—is, in these equations, taken as the zero point, merely for convenience of calculation. Whether the finite section surrounded by an infinite medium approaches the temperature of the medium from above or below that temperature, is immaterial so far as regards the form of the equations or curves. To reduce to the Fahrenheit scale, all that is required is to add 786, the temperature of melting zinc.

For example, consider a sheet of No. 24 gage, 0.025 in. thick. $X = \frac{0.025}{2 \times 12} = 0.00104$ ft. **k will be taken as 400. Btu per square foot, degree F. and hour.**

$\lambda_1 = 34$, $\lambda_2 = 65$ Btu per sq. ft. hour, deg. F. and ft. thickness. T_{11} is taken as the zero toward which all temperatures are approaching, and T_{12} is taken as $786 - 850 = -64$.

$$\frac{-400 \times 64.}{34.} = \tfrac{1}{2} A_1 \,.\, B_1 \,.\, \frac{2}{\sqrt{\pi}}$$

$$[1 - e^{-B_1^2 . (-0.00208)^2}]$$

$$-64 = \tfrac{1}{2} A_1 \,.\, G\,(0) - \tfrac{1}{2} A_1 \,.\, G\,[B_1 \,.\, (-0.00208)]$$

Solving graphically, $\tfrac{1}{2} A_1 = -376$, $B_1 = 73$.

$$T_1 = 376 \,.\, G\,[73 \,.\, (-X - x)] - 376 \,.\, G\,[73\,(+X - x)].$$

At the center of the sheet, $T_1 = -64.5$ deg. This means that the difference of temperature between center and surface of sheet can not exceed one-half of one degree F.

This result can be checked approximately in another manner, namely by comparing with a cosine curve having the same slope at point (15). It is well known that, after heat transmission has been in progress for some time, the space-temperature curves very nearly coincide with sine or cosine curves. Differentiating the equation

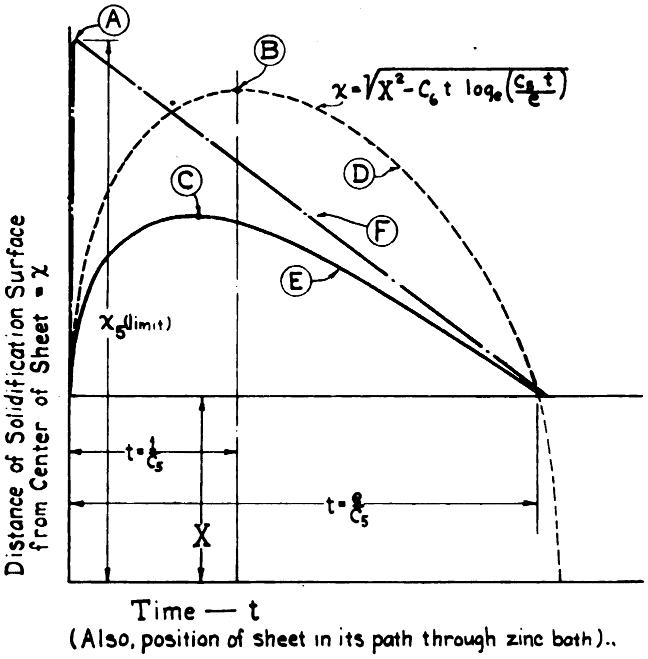

Fig. 5—Curves of motion of solidification or melting surface.

$$T = -64 - B_2 \cos\left(\frac{\pi}{2} \times \frac{X}{x}\right)$$

$$\text{gives } \frac{dT}{dx} = \frac{\pi}{2X} \,.\, B_2 \,.\, \sin\left(\frac{\pi}{2} \,.\, \frac{x}{X}\right),$$

$$\text{and for } x = X,\ \frac{dT}{dx} = \frac{\pi}{2X} \,.\, B_2.$$

But from equation (10

$$\frac{dT}{dx} = \frac{k\,(T_{11} - T_{12})}{\lambda_1} = \frac{400 \times 64}{34} =$$

752 deg. per foot.

$B_2 = 0.50$, and $T = -64 - 0.50 \cos\left(\frac{\pi}{2} \times \frac{x}{X}\right)$.

At the center of the plate, $X = 0$, $\cos 0 = 1$, and $T = -64 - 0.50$ or the temperature of the center of the plate would be 0.50 deg. lower than that of the surface.

If the plate were No. 16 gage, 0.0625 in. thick, and if **k** remained the same, 400 Btu per sq. ft., hour and deg. F., the greatest possible temperature difference between center and surface would be 1.3 deg. F. But the thicker sheet must move more slowly through the bath, and as explained in part I, **k** would decrease to about 120. for No. 16 gage sheet. The maximum temperature difference in that case would be 0.38 deg. F.

It may be well to repeat that these are the maximum or limiting temperature differences, and that the further the curve of motion of the zinc solidification surface departs from the form of (D), Fig. 5, and the nearer it approaches (F), the less is the temperature difference in the steel sheet.

While the above mathematical treatment is far from complete, it does at least show that, for any reasonable thickness of sheet, the steel is heated practically uniformly throughout; and that the time required for the surface to reach the galvanizing temperature is practically independent of the temperature gradient in the steel, and is directly proportional to the reciprocal of the rate of heat transmission.

PYROPHOROUS BLAST FURNACE DUST

The dust collecting in the upper portions of the shafts of blast furnaces and in the filter bags of dry gas purifiers is apt to catch fire spontaneously or when disturbed. At Wissen in Westphalia it was observed that the dust heaps would begin to smoulder in a few hours or days, especially heaps of very fine dust settling at some distance from the furnace. The still finer filter bag dust, weighing only about a quarter of the coarser blast-furnace dust, was worst, and the men had to be very quick and keep the gas suction going, when exchanging the gas bags, to prevent the bags from catching fire. The investigation started at Wissen on behalf of the Blast-Furnace Section of German Iron Men, on which J. W. Gilles reported in Stahl und Eisen, of June 8, pages 884 to 891, is not complete yet: but it shows that two substances are mainly responsible. The dust contained neither metallic iron (to be removed by magnets), nor metallic zinc, nor was it rich in carbon. But it was rich in manganous oxide, and at Burbach and Neuenkirchen (Saar district), where similar trouble had been experienced, rich in ferrous oxide; both these protoxides are known to be pyrophorous. Sulphides present in the dust do not seem to be concerned in the phenomenon, nor had the potash any influence, though the whole mass might become hot when the potash absorbed moisture. When the dust is once allowed to cool under exclusion of the air, it will not catch fire readily afterwards until heated up; but old dust heaps need only be stirred up with the shovel to begin to glow. The temperature to start ignition seems to range from 167 deg. C (fresh dust) up to 120 deg. C. (old dust). When the dust is heated in the presence of air so that the carbon is burnt out, and then cooled, and reheated in a current of hydrogen or of illuminating gas, it proves highly pyrophorous. **This treatment would result in the formation of protoxides of iron and manganese.**

Efficient Operation of the Blast Furnace

A Great Deal Can Be Done to Improve Stove Operation by the Application of Mechanical Draft—Forced Draft Burners Can Also Be Applied to Advantage.

By T. A. PEEBLES

IT is difficult to establish standards for operation involving the combustion of fuel which can be applied to a variety of conditions. This is especially true of blast furnace operation, because of the nature and number of variables to be considered. It may be assumed, however, that a modern furnace, producing 550 tons of pig iron per day, will have a 2,000-pound coke rate and will produce about 134,000 cubic feet of dry gas per ton of pig iron produced, with a heating value of 100 Btu. per cubic foot. This quantity of gas is considerably in excess of the amount required for heating the stove and producing the necessary power and auxiliary steam, so that the isolated blast furnace is not interested in the economical use of gas. This fact probably accounts for some of the inefficient practices that have developed in the past, even at furnaces so located that their excess gas might not be used in other processes of steel manufacture.

At many of the older furnaces 30 per cent of the gas generated will be used for heating the stoves and 35 per cent for auxiliary power, blowing, direct steam, etc., leaving 35 per cent available for outside power. A boiler plant operating at 60 per cent efficiency can develop 1925 hp. continuously from this quantity of gas. It has been assumed that the 35 per cent of the total gas which goes for blowing, auxiliary power, etc., is also used for producing steam under boilers, operating at an efficiency of 60 per cent.

It has been proven possible to operate blast furnace gas fired boilers at an operating efficiency of 80 per cent and if the 35 per cent of total gas used for blowing and auxiliary power had been used to generate steam at 80 per cent efficiency, instead of 60 per cent, the proportion of gas thus required would be reduced from 35 per cent to 26.25 per cent. At the same time more efficient combustion at the stove will reduce the gas required from 30 per cent of the total to 25 per cent or slightly less. The total gas required at the blast furnace plant is therefore 51.25 per cent, leaving 48.75 per cent available for outside power, which at 80 per cent efficiency will produce 3,575 boiler horsepower continuously, an increase of 1,650 horsepower over old practice.

This represents a very substantial saving, even in a large steel mill, where it is customary to deal in large quantities, and justifies a careful study of the problem.

It is first necessary to render as much gas available for boilers as possible, by most efficient utilization of that required to heat the stoves. Present practice consists of delivering the gas under whatever pressure exists in the main, drawing in the air for combustion by induction of the inflowing gas, and by the suction in the first pass of the stove. The burners are usually set to provide a sufficient quantity of gas when the line pressure is low, with the result that during times of normal or high pressure a considerable excess is being used. The variations in gas delivered also effects, to a certain extent, the amount of air supplied for combustion, but due to the variations of draft inside the stoves the introduction of air is not proportioned in accordance with gas delivered. Under such conditions, the most efficient combustion is impossible and an unnecessary quantity of gas is required at the stoves.

A great deal can be done to improve stove operation by the application of mechanical draft. Forced draft applied to the delivery of combustion air can be automatically regulated in such a manner that the correct quantity of air can be delivered in accordance with the quantity of gas being burned, and this correct proportion between air and gas will not be disturbed by variations in furnace draft. This can be accomplished by designing a burner which will give the correct proportions between air and gas, when the relative pressures are equal. Automatic regulation can then be applied to maintain the air pressure equal to the gas pressure and the correct heats of air and gas will be delivered, regardless of variations of draft inside the stove.

The application of induced draft to stove operation makes possible additional improvement in economy. The temperature of gases leaving a cold stove will be approximately 300 deg. F. and the draft available for removing products of combustion is, therefore, eliminated. As the stove heats up the draft capacity increases until a temperature of about 600 deg. F. is reached. When the temperature goes above this point the weights of products of combustion which the chimney can handle will decrease, because the density of the products of combustion decrease more rapidly than the velocity increases.

The application of induced draft makes it possible to overcome the difficulty and at the same time makes possible the use of a suitably designed recuperator. A hot stove will discharge the products of combustion at temperatures as high as 1100 deg. F. and a large amount of heat is lost. A suitably designed recuperator can be employed to absorb a substantial quantity of heat from the escaping gases, which can be used for preheating the combustion air, thereby improving the economy of the entire cycle and making possible higher stove temperatures, when desired.

The next step in the efficient utilization of blast furnace gas is to provide boilers properly designed for peculiar services with the most efficient type of burners. The boilers should have a long gas travel, in contact with the tubes, because the furnace temperatures are comparatively low and a large weight of gas is required per horsepower.

Forced draft burners can also be applied to advantage. There are two different types available:

First—Burners have definite areas of air and gas

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passages. In some cases equal areas are employed and the correct relation between air and gas pressure required for correct proportions are maintained automatically. The gas pressure is allowed to vary in accordance with the furnace operation and the air pressure automatically maintains the predetermined relation between air pressure and gas pressure. If unequal air and gas pressures are employed, it is important that uniform furnace draft be automatically maintained, because a variation in furnace draft has a different effect on the rate of flow of the air and gas, if they are delivered under different pressures. This objection can be overcome by employing burners designed to give the proper relation between air and gas, when the two pressures are equal. In this case a change in furnace draft effects both air flow and gas flow equally, and will not disturb the established proportions.

Second—The gas burners at the boilers may be designed to act as pressure regulators on the entire gas system. Each burner contains a damper for the control of air supply, and these dampers are automatically controlled from variations in gas pressure. A predetermined gas pressure is established, which it is desired to maintain automatically means provided for delivering the necessary quantity of air at a pressure equal to the gas pressure. The dampers in each boiler controlling the air supply and gas supply are operated in accordance with variations in gas pressure. An increase in gas pressure results in an increased opening of air and gas dampers, thereby maintaining an increased flow of both air and gas between them, in the correct proportions. On the other hand, a decrease in gas pressure results in a reduced opening of these dampers and the tendency, therefore, is to maintain constant gas pressure in the mains and to secure most efficient combustion of all the gases available for the boilers.

The burning of blast furnace gas has not kept pace with the development in the efficient use of other fuel, but there are many indications that blast furnace operators are prepared to give this matter the attention which its importance justifies. Suitable burners for properly proportioning air and gas, as well as automatic devices for their regulation, have been developed, and are in successful operation in a number of plants. These plants show better overall economy than plants operating without this equipment, the difference being much more than is necessary to justify the cost of installation.

Effect of Sulphur on Rivet Steel

Discussion of a Committee's Report On Effect of Sulphur On Rivet Steel, American Society For Testing Materials, June 28, 1922

By J. S. UNGER

FOR more than 40 years the question of the effect of Sulphur in steel has attracted the attention of metallurgists. Much study has been given to this subject, extending so far as to include the several chemical forms or combinations in which it exists, particularly in cast iron.

Within a period of 20 years, the tonnage of steel made by the two principal processes, the Bessemer and the Basic Open Hearth, has undergone a great change. In 1900 about 65% of the total tonnage was Bessemer—in 1920, 25%.

With the change in Processes came a change in the sulphur content in steel, the average sulphur in Bessemer steel being at least .065, against .040 in the basic open hearth. Structures of all kinds built from 20 to 40 years ago of Bessemer steel, are still in service today, being one of the best evidences that steel may contain a considerably higher percentage of sulphur than is permissible in present basic open hearth specifications, and still give years of excellent service.

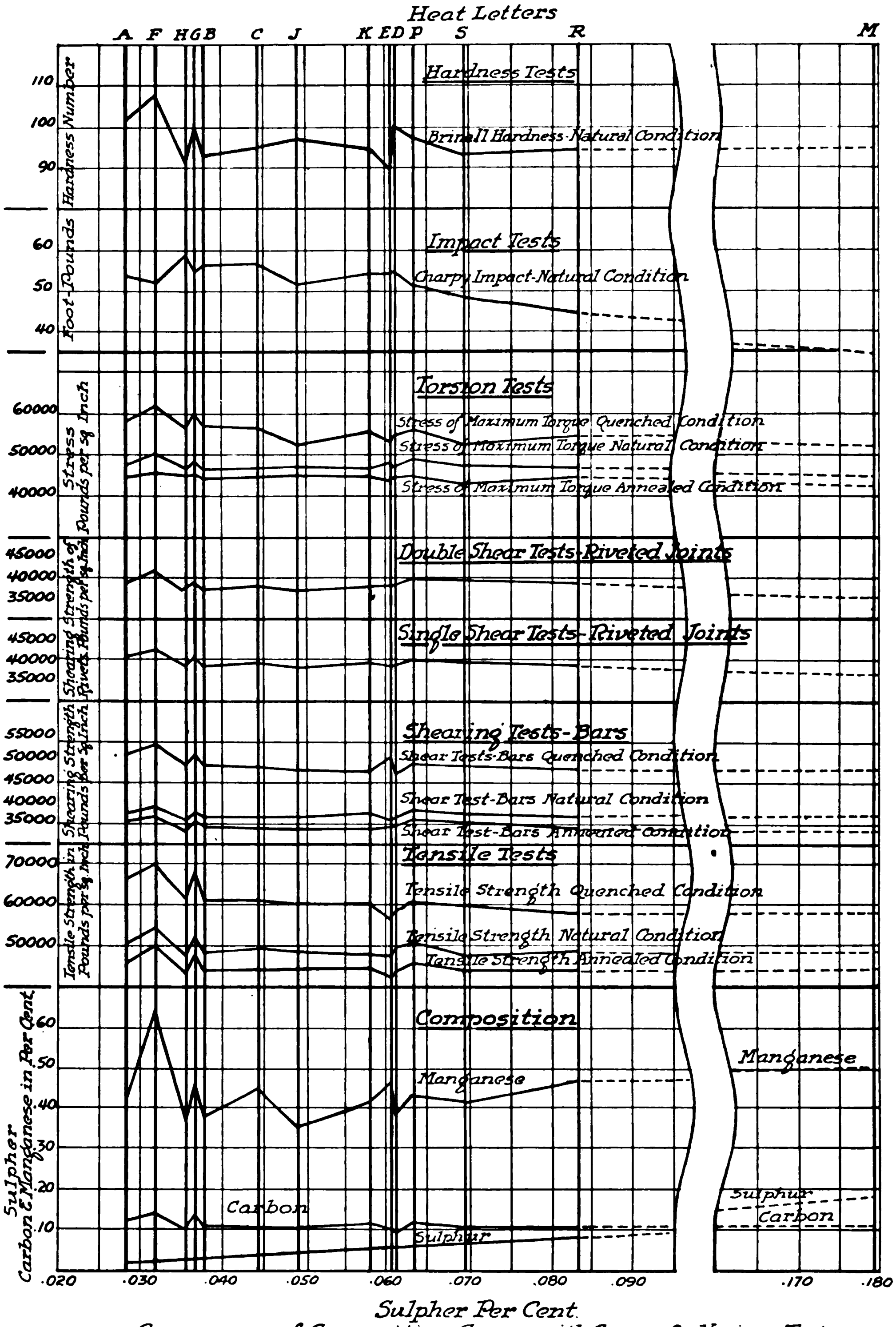
Additional evidence is found by making a study of soft, medium and hard steel parts, which have worn out in service, giving a good life, and which in many cases have contained more than .065 sulphur. On the other hand, equally convincing evidence is found for the same kinds of steels failing after a short time in similar service, in which the sulphur has been under .040. Evidence of the above kind is enough to make one hesitate in forming an opinion whether a reasonable amount of sulphur, say under .100, is detrimental or otherwise. These facts conflict with the generally accepted opinion that steel is of poor quality and should not be used for any important work, unless it be low in sulphur. I sincerely hope the committee will give this angle of their work serious consideration in their future studies.

In discussing the committee's preliminary report, I have copied graphs from their report, combining a number of their graphs on a single sheet and inserting a line for sulphur in order that it may be more easily and quickly comprehended.

In this chart, I have shown the composition curves for carbon and manganese at the bottom, adding a line for the sulphur content. Since ordinates and abscissas are in percentages of sulphur, the line for sulphur becomes a gradually rising straight line.

The effect of the Carbon and Manganese in the several heats is clearly shown by the approximate parallelism of the composition curves with those representing the Tensile, Shearing, Torsion, Impact and Hardness curves. All the curves for the physical properties are not shown as there is not sufficient space on the chart.

The striking thing in the chart seems to be that changes in the Carbon and Manganese content are immediately reflected by similar changes in the physical properties of the several heats with little, if any, change due to the increasing sulphur. It is almost impossible to make a number of heats of steel containing exactly the same percentage of carbon and manganese. Since this is true, it is practically impossible to determine the effect of sulphur if other variables in composition exist in the steel.



Comparison of Composition Curves with Curves for Various Tests.
"Discussion:-Effects of Sulphur on Rivet Steel."

Fig. 1.

In studying this same problem during 1915, I believed it best to use the same heat of steel, but to vary the sulphur content in the individual ingots of the heat. My results were given in full in a paper before the Society of Automotive Engineers, in January, 1916, and later in a paper before the American Boiler Manufacturers, in June, 1916.

Many persons are inclined to believe that sulphur added to steel does not have the same effect as residual sulphur remaining in the steel, but it is surprising how closely my results, obtained by added sulphur, check the results of the committee's work with residual sulphur, when allowances are made for the effects of the variations in the carbon and manganese in the several heats.

The committee's work was confined to rivet steel, but this same quality steel is used in making wire products, tubular products and sheets. The specifications for such products specifies the composition and sometimes calls for tensile tests and bending tests. The fitness of the steel is determined by the working of steel during fabrication and by such shop tests as flattening, bending, hydrostatic or heading tests. On pages 9, 10, 11 and 23 of the report, some shop tests were made, showing very little differences among the steels. These are some of the commercial tests employed by the user to show whether the steel is of good quality, yet the committee, beyond stating what was done have not made any comment on the quality. Instead physical or mechanical tests of many kinds were made, very few of which are ever regularly used in the arts, and the graphs presented to show the quality.

I have examined the complaints or claims for rivet steels covering a period from 1911 to 1922 or 11 years.

They show the following percentages:

For Quality	
Mixed steel, and Tensile Strength	15%
For Surface	
Mechanical Defects, Seams, Pipe, Split Heads	28%
For Rolling	
Out of round—Variation in Size	6%
For High Sulphur	51%
Total	100%

This table shows that more than one-half of the complaints were due to high sulphur, in most cases causing the rejection of the steel without any effort being made on the part of the user by shop or service tests to see if the steel was really bad or unfit for use.

The committee has refrained from drawing conclusions from their work. The graphs are not easily understood by the layman. Considerable time has elapsed since the work was begun. Probably a much longer time will be needed for the study of the medium and harder varieties of steel. In the meantime, much commercially good steel is being thrown away. The producer and consumer are awaiting the verdict.

I ask the committee to hasten their work, drawing conclusions as they proceed and completing the work at an early date. This will be of great benefit to our society, settling, partially at least, a controversy of many years standing.

Economically Burning Liquid Fuel

Factors Affecting the Use of Air in Oil Burning With Comparison of Cost.

By W. C. BUELL, JR.
Buell, Scheib and Mueller, Inc., Pittsburgh, Pa.

THE question of the advantages to be found in burning liquid fuels with air under various pressures has been the subject of considerable discussion, but little has been written on the subject and figures of comparative performance are entirely lacking.

This subject is one of sufficient importance for a careful analytical discussion, as the summary at the end of this paper will show. As nearly every industry burns more or less oil or tar the subject is one of quite general interest, and a consideration of the summary of the analysis made hereafter will clearly show that it is possible to waste a large amount of money in purchasing a selected fuel or in using air that must be reduced in pressure to meet the requirements of combustion.

An examination of the oil burning systems offered for industrial heating practice will indicate that there are three general types of oil burners classified on a basis of air pressures at the source of supply from which they operate, and somewhat along the following line:

(a) Those burners employing so-called "volume" air which is moved by high speed fan blowers and delivered to the burners at pressure from 4 to 10 or 12 ounces.

(b) Those burners operating on so-called "positive" air which is delivered to the burners by displacement or turbine type machines and occasionally by very high speed centrifugal fans, at pressures ranging from 12 ounces to 2 pounds.

(c) The burners utilizing "high pressure" air which is delivered to the burners from compressor lines in which pressures ordinarily run from 50 to 60 or 100 pounds gauge.

Each of the three foregoing systems has its advocates and it is usual for the manufacturers of oil burning equipment to follow the lines of least resistance when making recommendations and to propose equipment using the air pressure which is favored by the customer rather than to stand on sound engineering principles and to recommend equipment operating under the best economic conditions.

It is the writer's purpose to discuss at some length all of the factors affecting the use of air in oil burning under the above classifications, but with reference to Class A equipment it should be understood that burners operating on the low pressures of this classification cannot depend on the air to atomize the oil, but must of necessity use a mechanical system, in which the oil fuel is atomized by the static oil pressure forcing the oil fuel through very small orifices in the form of a fine spray which the low velocity air can easily pick up.

The use of this system is limited to oil which is very fluid and very clean; viscous or dirty oils will cause partial or complete cessation of operation and with the necessity for the conservation of the petroleum resources of the country clearly before us, it is an unnecessary

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*Abstract of paper presented before Engineers' Society of Western Pennsylvania.

waste of the natural lubricating and potential chemical reserves of the country to use as fuel selected distillates of high Baume gravity, the only kind which can be used successfully in the mechanical system as applied to furnace practice. As a matter of fact, in this day and age only residue and heavy fuel oils should be considered as fuels.

A few manufacturers still offer "volume" systems. The more progressive propose the "positive" system, while quite a number advocate the use of "high pressure" systems, while plant engineers are prone to specify "100 pound air is available and will be used."

Air Velocity at Various Pressures.

A study of the dynamic head or velocity coming from the static air pressure when discharged against the atmosphere (which throughout this paper is assumed to be 14.7 pounds pressure absolute at 70 deg. F.) will show that at one inch water pressure the velocity will be 70 feet per second, at one pound the velocity will be 352 feet per second, and at four pounds over 700 feet per second. If we calculate still further on the basis that four times the pressure will double the velocity we will find that at 64 pounds gauge pressure the velocity will be approximately 2,800 feet per second. Of course, at the common 80 pounds gauge pressure for compressed air delivery the velocity will naturally be still higher.

It must not be assumed that air passes into the burner setting at anything like the velocities that are a function of high pressure air. Velocities are very much reduced by permitting the air to expand through the controlling valves and it is the writer's opinion, based on observation, that combustion can never be sustained when air enters the burner setting in excess of approximately 600 feet per second, which is the equivalent dynamic head coming from approximately 3 pounds gauge static pressure; in ordinary combustion practice, velocities must be not greater than 100 feet per second 6 or 8 inches ahead of the burner nozzle if good results are to be secured.

It will be shown that the comparative cost of compressing air at 2 pounds, which produces an ideal combustion condition, is somewhat higher than the cost of compressing air initially to approximately 15 pounds gauge, and while air is seldom furnished by machines delivering it at an initial pressure of 15 pounds, the use of air initially compressed to 15 pounds offers interesting cost possibilities under certain installation conditions.

Functions of Velocity.

In oil burning practice air velocity has two general functions: First, to atomize or shred the oil fuel into minute globules, thus increasing the surface exposed to the volatilizing effect of the air stream and placing the oil in a gaseous or semi-gaseous form in order to burn it as rapidly as possible; and, second, to induce the greatest possible amount of atmospheric air which may be secured through aspirator action in the throat of the setting and which may be frequently greatly increased by proper setting and burner design.

Velocities for Atomizing.

It will be conceded that in burning oil a certain standard practice must be established, based on good engineering principles, in order to secure the most satisfactory operation and this is especially true where it is desired to use the heavier grades of oil.

According to the writer's experience, the general statement can be made that if oil reaches the burner tip at a viscosity of not more than 300 seconds on the Saybolt viscosimeter satisfactory atomizing will take place if the air column meets the oil at pressures from 12 ounces to 15 pounds.

Saybolt seconds divided by 30 will give the ratio of fuel flow as compared to water and therefore, 300 Saybolt seconds means that oil may be used that is 10 times as viscous as water under equal conditions (temperatures excepted); in other words, a volume of oil that requires 10 times the amount of time required for an equal volume of water in the apparatus to flow through a given orifice under similar conditions will have a viscosity 10 times that of water.

Heating the oil is usual practice to reduce the viscosity of fuels that at ordinary temperatures are too viscous to atomize by air action. With all commercial oils offered for fuel today the viscosity of 300 Saybolt seconds will be secured at temperatures under 250 deg. F., and this seems to mark the maximum working limits of oil heating, as at high temperature oils may to some extent decompose, possibly gasifying to some degree and also have a tendency to deposit solid carbon; therefore, it may be safely said that 300 seconds Saybolt viscosity is the maximum limit allowable in oil burning. Therefore, in designing oil burning systems, the air system should be predicated for a fuel having a fluidity of 300 Saybolt seconds.

Velocity Found in Combustion.

On this subject a number of assumptions must be made. Some research has been done, notably on pure hydrogen, to determine the rate of flame propagation and with air at atmospheric temperature and constant pressure it would seem that the speed of back fire of hydrogen is approximately 14 feet per second. This means that if hydrogen is mixed in proportion with a column of air having a velocity in excess of 14 feet per second the air velocity will blow the point of combustion away from the point of mixing, while if velocity falls below the rate of 14 feet per second the hydrogen air mixture will burn back to the point of mixing.

Little work has been done or at least published on the subject of rate of combustion of the hydrocarbons, the information is at the best unreliable and, like the figures for hydrogen, the results apply merely to laboratory practice. From such data as the writer has been able to collect and from observation in many years of combustion research work he believes that the speed of back fire in Pittsburgh natural gas is about 8 feet per second with air in proper proportion and that in the case of fuel oil it is considerably lower and probably in the neighborhood of 5 feet per second, these results, of course, being found at constant pressure and atmospheric air temperatures.

Assuming the writer's figures to form a basis for consideration of the combustion of commercial fuels, it may, therefore, be stated that an air oil mixture entering a cold combustion chamber with a speed in excess of 5 feet per second must be broken down to approximately that figure (at least) before combustion will be sustained.

A simple phenomenon which will illustrate this is very frequently observed when endeavoring to light an air oil mixture in a cold furnace. The air oil mixture travels into the furnace perhaps several feet before combustion is sustained at all, then often very poorly, but as the combustion chamber heats up, radiant heat from the setting is focused on the entering an oil column, and as the mixture preheats, the point of combustion works back until combustion is sustained in proximity to the burner tip. As a further example, it is quite often observed that in order to sustain combustion at all in a cold furnace a baffle brick must be placed a foot or so ahead of the burner upon which the air oil column impinges, breaking up the velocity of a part of the column at least, practically to zero. When starting it is hard to maintain satisfactory combustion, but as the baffle brick heats up, the heat of the brick supports the combustion of the air oil mixture. A baffle brick used as described is an indication of faulty condition in the oil burner or setting.

It must not be assumed that it will be desirable to introduce the air oil mixture at a velocity as low as the speed of back fire. Excessively low velocities in the mixture, when the furnace is hot, have a tendency to make the resulting combustion altogether too "soft." As a matter of fact, it is customary to introduce the mixtures with a velocity of perhaps 60 to 80 feet per second, which, while it may make the lighting of a cold furnace somewhat troublesome, will permit a very excellent combustion condition. After a burner setting has become sufficiently heated to radiate heat to the air oil column, and the air oil column is heated beyond the ignition point of the mixture (which is relatively low and probably in the neighborhood of 700 deg. F.), combustion takes place and is sustained readily with velocities up to approximately 100 or 120 feet per second; these are, however, unduly high and usually produce the severe "blow piping" action which causes rapid failure of the refractories on which the flame may impinge. It is only by preheating the air oil column to a considerable degree that combustion is sustained with desirable velocities, which from the writer's observation appear to be about 65 feet per second. From the foregoing it will be seen that energy expended in compressing air to a point that will produce velocities much above 1,000 feet per second is a considerable waste of money.

Reduction of Velocity.

In oil burning practice the velocity of the entering air must be broken down to the combustion speed equilibrium as quickly as possible, and at a predetermined distance from the burner tip in order to secure the liberation of the heat within the most desirable space.

This is accomplished in several ways, singly or in combination as follows.

The expenditure of dynamic energy in the mechanical air by atomizing or shredding the fuel is one means of reducing the velocity. The expenditure of energy in inducing atmospheric air is another. Friction in the metal burner funnel and fire brick setting has a material reducing effect, as does the expansion of air in the burner setting and the impingement of air oil mixture on the surface of the brick work. A sudden change of direction of flow has a great reducing effect, but possibly the expansion of the air oil column within the setting and the combustion chamber is the greatest single factor tending to reduce velocities, it being assumed that furnace pressures are but slightly above the atmosphere.

Quantities of Air Required for Burning Fuel Oil.

The amount of air required for combustion of fuel oil varies from 1,250 cu. ft. per gallon in the case of a light oil approaching kerosene, to 1,700 cu. ft. per gallon with heavy oil approaching 10 deg. Baume, or from 192 to 220 cu. ft. per pound. Usually air in excess of that required for perfect combustion is present in the combustive reaction and excess air in itself is the source of one of the greatest fuel wastes. To a marked degree the use of excess air may be eliminated by proper engineering, the selection of the air mover and the design of the air distributing system, the burners and the setting.

In nearly every case, excepting only a few special heating operations, it may be taken that perfect combustion produces the most desirable furnace atmosphere and anything that will assist in securing approximately perfect combustion will produce a saving of considerable magnitude.

It should be understood that perfect combustion is never accomplished commercially except instantaneously, as there are many variables affecting the reaction which are continually acting to change the proportions of air and fuel, but excess air to the extent of 5 or 10 per cent should mark a maximum in liquid fuel practice, and this may easily be accomplished with a properly installed system.

Oil Burning Practice.

If the opening through the furnace wall through which the combustive mixture of oil and air passes is correctly designed and if the flues and other passages within the furnace are so proportioned that no undue pressure is set up within the furnace a considerable amount of atmospheric air may be induced by the action of the air from the mechanical compressor and thus the size of the blowing apparatus may be held relatively small.

In the case of "volume" air as defined in the "A" classification, the best conditions that may be secured average about two parts blower air to one part atmospheric air induced; or, in other words, for every 1,000 cu. ft. of air required for combustion 650 ft. must be supplied by the blowers.

In the case of "B" classification or "positive" air, from 45 to 70 per cent of all air required for combustion may be induced, or for every 1,000 cu. ft. required only 300 to 550 ft. need be supplied by the compressor.

The cost of air per gallon with a compressor at 15 pounds is the lowest consistent with good atomizing and combustion conditions and it is shown that the cost of power for compressing is 80 pounds is over four times as great. The cost per gallon with one and two pound turbine type machine will likely be found the most economical in practice in the great majority of cases.

As has been previously stated, air supplied by the machines under the "B" and "C" classification will atomize heavy oil where those in the "A" classification will not. The cost of compressing at .0012 cents per gallon for 8-ounce air would make a most excellent argument in favor of the mechanical system were it not for the fact that the selected oil required for good operation with this system would put a premium of at least 25 per cent on the oil cost in a normal fuel market, making the cost of the selected oil .05 cents per gallon when the heavy oils are available at .04 cents.

Operation of one and two pound turbine machines places a cost of .002 and .0025 cents respectively per gallon on the oil fuel, while the operation of 15 pound piston machine adds a cost of .0015 cents per gallon and the 80 pound piston machine .006 cents per gallon.

Conclusion.

Consideration of the subject matter and figures of this paper should clearly show that the proper method of burning oil is with air pressure under the "B" classification or under some conditions with 15 pound air under the "C" classification.

Steam Turbines and Electrical Drives for Vital Auxiliaries

Coordinate Use of Steam and Electrical Units Assures Continuity of Operation and Economical Heat Balances.

By LINN HELANDER*

CONTINUITY of service, such as is demanded of the vital auxiliaries in steel plants, can only be assured by the co-ordinate use of steam and electrical units. In view of the growing concentration of steel-mill electrical power-generating apparatus, complete disruption of electrical service must be considered an increasing likelihood. Where but a single source of power is available, therefore, simple electrification of such auxiliaries as those in the water-pumping plant and the power plant is a hazard which is not warranted by the consequent savings either in investment charges or operating charges. These charges are negligible with respect to the value of the service that the auxiliaries provide and they should not, therefore, be a determining consideration except as a basis for making a choice between equally reliable layouts. Neither should the effectiveness of the heat balance be permitted to lessen the reliability of these auxiliaries, though careful consideration will usually reveal an arrangement which assures continuity of operation and good economies without excessive investment charges.

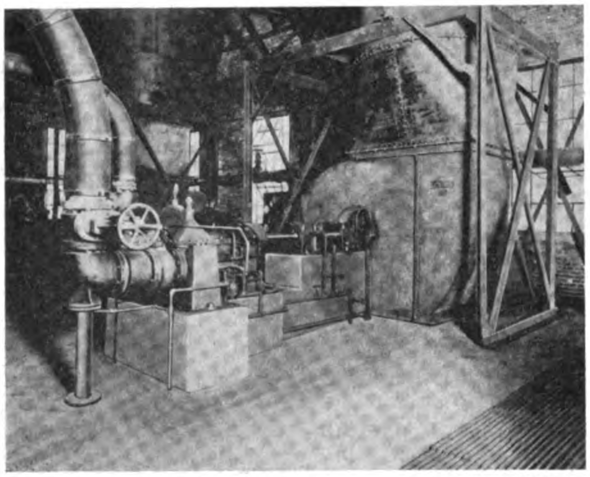

Fig. 1—Geared turbine unit driving induced fan. The gear, it will be noticed, is entirely enclosed so that dust, usually found in a boiler room, will not effect its operation.

Probably the most important part of a steel plant, judged from the necessity for continuous operation, is the main pumping station. Upon this station depends the continuous operation of all mills and furnaces, so that even a short interruption in its service will result in serious loss of production and very likely in disastrous accidents at the blast furnace. The value of the service of the main pumping station is, therefore, equal to that of the entire steel plant, and the value of its continuous service exceeds the value of the continuous service of the rest of the plant by the extent of damage likely to result from a sudden shutdown. Reliability in this case must be complete. The problem is not how much should be spent, but what is the best expenditure.

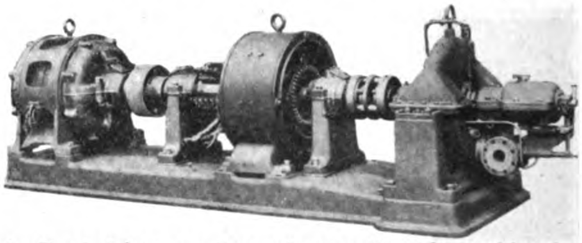

Fig. 2—Dual driven exciter—observe that the turbine is supported by pedestals at its center line. The simplicity of the arrangement, together with the availability of both steam and electric power, makes this unit essentially reliable.

When steam is the only primary source of power in a steel plant generating its own power, reliability of service requires steam-driven apparatus, with or without the coincident use of electrically-driven apparatus. With this in mind, the main pumping station and the auxiliary pumps supplying the blast furnaces with water should be placed as closely as possible to the main boiler room. This probably will offer no considerable difficulty with regard to the auxiliary pumps. For the main pumping plant, however, it may require, if the ground be sufficiently level to warrant the expenditure, rather extensive tunneling. It is then the problem of the designing engineer to balance the fixed charges on the cost of tunneling against the fixed charges and operating costs of the steam piping and the electrical transmission lines. When a sufficient difference in level exists between the river and the boiler room, tunneling probably will be profitable only up to the point at which an abrupt rise occurs. Also, in this case it is likely that two pumping stations will be required; one at the river to pump the water to a sump at the level of the power plant, and another to take the water from this sump and pump it to the head tank and to the various parts of the mill. Reliability of service requires steam equipment in each of these pumping stations. The auxiliary pumps, however, may be located close to the boiler room, while the main pumping station will no doubt require rather extensive steam piping.

Though steam-driven pumps are a prerequisite to reliability, increased reliability, sufficient to warrant the necessary investment, is obtained by using, in addition, electrical power. The use of both steam and electricity not only provides two means for the transmission of power to the pumping station, but also makes for flexibility in the layout of the pumping apparatus and permits distributing the service between electrically-driven and steam-driven units so that advantage may be taken of the economies that such distribution may effect. What the layout and distribution of loadings between steam and electrical apparatus should be depends upon the size of the pumping station, the heat balance and other conditions inherent to the particular plant under consideration. Considerations of various arrangements, however, will illustrate the possible advantage of combined electrical and steam-driven pumps and the problems that the designing engineers must solve.

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*General Engineer, Westinghouse Electric and Manufacturing Company.

The heat balance for a steel plant can no doubt be worked out by making use of the auxiliary pumping station, the boiler-room auxiliaries, and the power-plant auxiliaries. The main pumping station also should be considered in this connection if it is not exceedingly remote from the boiler room. It is likely, however, since there is a practical limit to the distance low pressure steam can be carried profitably for heating purposes, that this plant should, preferably, be kept independent of the heat-balance layout. If this is done the problems in connection with it are principally the determination of the number of pumping units to be installed and the kind of drives to be used.

The minimum number of pumps for reliable service is three: Preferably four or more, depending on the size of the plant, may be installed. If three pumps are installed, two of these may be motor driven and one steam driven, or two may be steam driven and one motor driven, or dual drives may be used. When either three or four pumps are installed, two of these should be sufficient under the most severe conditions to take care of the demands on the station. If analysis indicates that motor-driven units for usual service give better economies than those obtainable with steam-driven units, the problem remains as to whether the spare steam unit, or units, should be dual driven or straight steam driven, and whether they should be provided with condensers or should exhaust to the atmosphere.

When three units are installed, the spare unit will be called upon not only when the source of power for the normally operating units is disrupted, but when, due to breakdown or other necessary outages, one of these units is out of service. Upon the frequency of the outage will depend largely the economies desired of the spare unit. If this spare unit is arranged so that it may be driven by either a turbine or a motor, that is, if it has a dual drive, outage of a normally operating unit will not involve a change in the source of power. The economy of the drive operating on steam in this case would not necessarily be a consideration. The unit rarely would be called upon for service and the prime consideration would be rugged and simple construction to provide the maximum assurance of response to sudden demands for its service. It should not, therefore, be encumbered with condensers. The dual drive has the additional advantage of providing a double assurance that the driving end of a spare unit will not be out of service. Its construction is simple and its immediate response to changes in the source of power makes it a highly desirable unit for this service.

When the spare unit is driven only by a steam turbine the choice between condensing operation and non-condensing operation rests upon the cost of steam, and upon the frequency with which the unit will be called upon for its service. If condensers are provided, a small, but nevertheless, additional hazard is put upon the spare unit, so that a desirable arrangement in this case would be two motor-driven units and two steam-driven condensing units. This would seem a desirable arrangement for a large plant, though for a small plant it is likely that a straight non-condensing unit would be preferable. It should be kept fully in mind that when three units are installed and one is a spare, the capacity of any one unit must be amply sufficient to provide for all the vital needs of the steel plant.

As regards the auxiliary pumps, the boiler-room auxiliaries and the power-plant auxiliaries, these are so closely related to the heat-balance that they cannot be properly selected without previous knowledge of the amount of low-pressure heating steam required. This heating steam should be sufficient not only to provide for heating the feed water, but also for heating the buildings during the winter months.

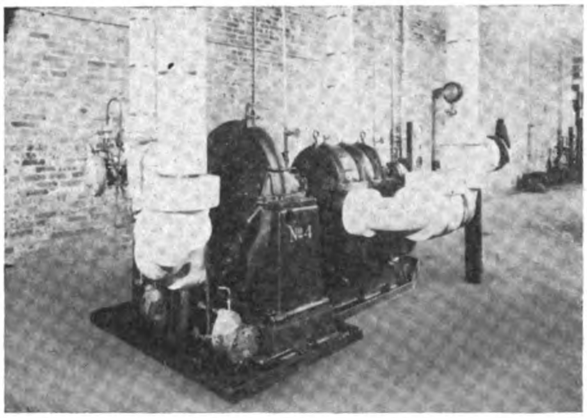

Fig. 3—The compact simplicity of a turbine-driven boiler feed pump, as compared with a reciprocating pump, is evident. Reliability of operation is further assured by supporting the turbine on pedestals at the center line. This permits free expansion of the casing without strain due to misalignment.

If a closed feed-water heater is used so that the pressure on the exhaust steam line may be maintained at 3 to 5 lbs., the building heating system profitably may be tied-in with the feed-water heating system. In this case, when all the auxiliaries are steam driven, waste exhaust steam should be avoided by returning any excess to the low-pressure blading of the main generating unit. A more satisfactory layout from the viewpoint of reliability, and one which has measurable advantages respecting heat balances, provides duplicate motor driven and steam units. This permits distributing the load between the steam and electrical drives so as to maintain at all times a desirable heat balance. Dual drives could profitably be used for this purpose as they provide a ready means for distributing the load between the steam and electrical drives with assured reliability.

When an open type of feed-water heater is used, the steam required for heating buildings should be obtained from a source independent of that supplying the feed-water heater. A convenient arrangement would be to provide the auxiliary pumping station with duplicate steam and electrically-driven apparatus. The steam-driven apparatus should be designed to operate against a back pressure of approximately 5 lbs. gauge and to deliver sufficient exhaust steam to supply the needs of the winter heating load. During summer months the motor drives should be operated. Dual drives also would have advantages in this connection.

As already intimated, the exciters, boiler feed pumps, and the units in the auxiliary pumping station should have both steam and electrical drives to assure against disruption of service. Forced-draft fans, induced-draft fans and condenser-circulating water pumps may be either steam or electrically driven. The choice will be based on the heat balance requirements and the economies obtainable by motorizing, taking into account probable losses due to disruption of the electrical source of power. Preference, however, should be given to an arrangement which provides both steam and electrical drives and, particularly in the boiler room, the straight steam drive should be looked upon as preferable to the straight electrical drive.

When waste-heat boilers are used on the open-hearth furnaces, the steam supplied by them probably will be sufficient to furnish the full needs of the gas producer and also leave additional steam for other uses. This steam should be used for developing power. To this end auxiliaries in the neighborhood of the waste-heat boiler should be provided with turbine drives. These preferably should have dual drives, and should be arranged so that during winter months the exhaust steam may be fed into the building heating system at the same time allowing for condensing operation during the summer months. The reduced load carried by the turbines during their winter-condensing operation would then be taken by the motors.

Parallel operation of steam-driven auxiliaries and motor-driven auxiliaries, together with the use of exhaust steam for feed-water heating, makes the use of centrifugal apparatus highly desirable. Centrifugal turbine-driven pumps provide a continuous non-pulsating flow of water which imposes no unusual conditions on the motor-driven pumps. Reciprocating steam-driven pumps, on the other hand, provide a pulsating flow of water. At each piston stroke the pressure in the discharge piping moves to a high and a low value. This variable head is carried to the motor-driven centrifugal pump and, inasmuch as centrifugal pumps are quite sensitive to changes in pressure, causes the flow from these to pulsate in unison with the reciprocating apparatus. This not only is undesirable from the viewpoint of maintenance but it also tends to lower the efficiency at which the system operates. Reciprocating pumps also discharge oil from the steam cylinders along with the exhaust steam and this oil, when carried to the boilers through the feed-water heating system, causes operating difficulties in connection with the generation of steam. Other advantages credited to the centrifugal pump as against the reciprocating pump, such as less floor space, smaller maintenance charges, flexibility, ease of regulation and greater efficiency, have been so largely demonstrated in practice, that modern feed-water pumping installations are practically invariably centrifugal pumps. A 300 g.p.m. reciprocating boiler-feed pump would require, for example, 65% more steam for the same service and 230% more floor space than a centrifugal pump.

Association of Iron and Steel Electrical Engineers Convention in Cleveland

The sixteenth annual convention of the Association of Iron and Steel Electrical Engineers will be held September 11 to 15 at Cleveland Public Hall, Cleveland, Ohio, at which there will be presented and discussed subjects dealing particularly with steel mill problems.

In addition to the meeting, an exhibition of electrical equipment will be shown in the Exhibition Hall. Here 65,000 sq. ft. of floor area will be used to exhibit the equipment of the various electrical companies.

The following program, which has been arranged by Mr. J. H. Kelly, Secretary of the Association, includes some particularly interesting papers, among which are the following:

"Improvement in Efficiency of Electric Power Supply," Dr. Charles P. Steinmetz, Chief Consulting Engineer, General Electric Company, Schenectady, N. Y.

"A Review of Steel Mill Electrification," B. G. Lamme, Chief Consulting Engineer, Westinghouse Electric & Mfg. Company, East Pittsburgh, Pa., and Wilfred Sykes, Assistant to Operating Vice President, Steel & Tube Company of America, Chicago, Ill.

"Judging Combustion from Gas Analysis," A. G. Witting, Assistant Chief Engineer, Illinois Steel Company, Gary, Ind.

"Electrification of the International Nickel Company's Works for Monel Metal," F. C. Watson, Electric Superintendent, International Nickel Company, Huntington, W. Va.

"The Gas Engine as a Prime Mover for Power Generation," D. M. Petty, Electrical Superintendent, Lehigh Plant, Bethlehem Steel Company, South Bethlehem, Pa.

"Steam Turbines," L. W. Heller, General Superintendent Power Stations, Duquesne Light Company, Pittsburgh, Pa.

"Some Considerations in the Electrification of the Steel Plant Railroad Yard," R. B. Gerhardt, Electrical Superintendent, Bethlehem Steel Company, Sparrows Point, Md.

"Power in the Iron and Steel Industry," D. B. Rushmore, Consulting Engineer, General Electric Co., Schenectady, N. Y.

"Boiler Practices of 1922"—Topical Discussion, J. B. Crane, Combustion Engineer, George T. Ladd Company; E. R. Fish, Vice President, Heine Boiler Company; R. M. Rush, Springfield Boiler Company; R. E. Butler, Babcock & Wilcox Company; F. Hodson, Electric Furnace Construction Company; Prof. Edgar Kidwell, Gen. Mgr., Kidwell Boiler & Engineering Co.

"Control Standardization," F. W. Cramer, Engineer of Tests, Cambria Steel Company, Johnstown, Pa.

"Motor Standardization," D. M. Petty, Electrical Superintendent, Lehigh Plant, Bethlehem Steel Company, South Bethlehem, Pa.

"Investigation of Insulators for Steel Mill Service," A. R. Leavitt, Engineer of Tests, Carnegie Steel Co., Duquesne, Pa.

"Electric Furnaces," E. T. Moore, Electrical Engineer, Halcomb Steel Company, Syracuse, N. Y.

"Lighting in Steel Plants," R. H. Bauer, Electrical Engineer, Carnegie Steel Co., Clairton, Pa.

"The Question of Safety in Steel Mills," F. A. Wiley, Electrical Superintendent, Wisconsin Steel Company, Chicago, Ill.

"Education," L. F. Galbraith, Electrical Superintendent, West Penn Steel Company, Brackenridge, Pa.

"Electrical Developments in 1922," R. B. Gerhardt, Electrical Superintendent, Bethlehem Steel Co., Sparrows Point, Md.

"Crane Standardization," R. S. Shoemaker, Superintendent of Maintenance, American Rolling Mills, Middletown, Ohio.

The Decomposition of Martensite into Troostite in Alloy Steels*

By HOWARD SCOTT†

ABSTRACT

The effect of the alloying elements, manganese, silicon, nickel, cobalt, tungsten, chromium, vanadium and molybdenum, on the decomposition of martensite to troostite was determined by means of heating curves. Only three of these elements showed a marked effect, namely, manganese, silicon and chromium. The first named increased the intensity of the transformation, while the last two raised its temperature when present in certain percentages. None of the alloying elements lowered the transformation and no general relation was found to exist between it and the higher critical point Ac_1. The significance of these data in regard to the heat treatment and properties of alloy steels is discussed.

THE significance of the critical point A_1 in steel and its relation to heat treatment is now fairly generally understood. There is, however, a transformation of nearly equal importance which occurs at lower temperatures on heating hardened steels and which is not widely recognized. It is intimately connected with the phenomenon of tempering, but has escaped the critical attention it deserves because the more common physical tests do not reveal it plainly. However, the development of thermal analysis apparatus which operates effectively in the low temperature range involved has made possible the convenient and accurate detection of the small heat effects associated with the transformation.[1] By means of this tool the essential characteristics of the phenomenon under discussion have been studied and their relation to the changes in certain physical properties of plain carbon steel on tempering pointed out.[2]

The evidence presented and reviewed in the above reference indicates that the transformation designated as Ac_t, which manifests itself as a heat evolution, marks the decomposition of martensite into troostite, a change of obvious importance in steel treating. This change which begins at about 170 deg. C., after slowly increasing in intensity reaches a maximum at 270 deg. C. and ends at 290 deg. C. for a normal rate of heating. However, on slower heating it occurs at lower temperatures consequently at a given temperature on the normal heating curve it has not progressed so far as if it were tempered a long time at that temperature, that is, as if heated at the hypothetical zero rate. For that condition the maximum is at 250 deg. C. and the end at 260 deg. C., which values are independent of the carbon content or quenching temperature.

It might be expected that alloying elements in steel will change the position of this transition and that some of the new properties conferred by the alloy may be due to that effect alone. Also there is the possibility that a knowledge of the characteristics of the change might aid in the interpretation of anomalies met with in the treatment of alloy steels. In recognition of these possibilities thermal curves were taken on the alloy steels available which represented eight of the principal alloying elements. The effect of rate of heating was not determined, but it is quite probable that it is very much the same as in carbon steels when the alloy does not change the transformation characteristics markedly.

Experimental Data.

The details of the experimental method used have already been noted in the papers mentioned so the tabulated data only are given here with a few representative curves, Fig. 1. In Table 1 are given the percentages of appreciably variable elements with the quenching temperature and medium used. The small size specimen used, about 2 grams in weight, prohibited the formation of troostite on quenching in oil as well as in water. The rate of heating is that just before the start of the transformation. The temperature of the three principal inflections in the curves are recorded under beginning, maximum and end when definitely discernible. The maximum is of course the most readily observed and important feature of the heat evolution. The intensity of the transformation has been indicated in the table by arbitrary values which are relative only. The last column gives the temperature of the maximum of Ac_1.

In order to compare the data for the alloy steels with those for carbon steels, the results from two carbon steels of 0.44 and 0.73 per cent C. content are given as these represent closely the carbon contents of most of the alloy steels used. From another viewpoint they represent also the class of structural steels and of tool steels respectively. Since all the commercial steels investigated contained both manganese and silicon, the effect of these two elements may properly be considered first. These elements have a decided though quite different effect on Ac_t. Manganese in the percentages employed increases the intensity of the heat evolution, but not the temperature appreciably. In fact the increased heat effect accounts for the

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†Associate Physicist, Bureau of Standards of the U. S. Department of Commerce.

[1] Scott & Freeman, B. S. Sci. Paper 348, A. I. M. E. Pyrometry Volume, p. 214, 1920.

[2] Scott & Movius, B. S. Sci. Paper 396, A. S. S. T., 1: 758 (1921).

TABLE I

Composition				Quenching Temperature °C	Quenching Medium	Rates of Heating °C/sec.	Ac_t (°C)			Intensity	Ac_1 Maximum °C
% C	% Mn	% Si	% Alloy				Beginning	Maximum	End		
CARBON STEELS											
0.44	0.36	0.06		900	water	0.12	174	270	286	3.0	731
0.73	0.29	0.01		900	"	0.12	175	271	292	7.0	731
PURE Fe-C-MN ALLOYS											
0.28	1.35			900	oil	0.12	174	269	288	1.3	725
0.44	1.00			900	"	0.13	174	276	297	6.0	727
0.90	1.61			800	"	0.13	...	276	307	12.0	718
0.90	1.61			800	"	0.11	169	277	307	16.0	727
SILICON STEELS											
0.70	0.41	1.98		900	water	0.12	...	454	473	2.5	...
0.70	0.41	1.98		1100	oil	0.16	...	458	475	2.5	767
0.41	0.86	3.00		900	"	0.16	...	481	498	2.0	790
NICKEL STEELS											
0.38	0.66	0.16	Ni 2.00	800	oil	0.12	186	281	296	1.5	706
0.38	0.66	0.16	Ni 2.00	800	"	0.12	171	281	300	2.5	707
COBALT STEELS											
0.62	0.34	0.43	Co 4.96	900	oil	0.15	...	277	305	2.0	766
TUNGSTEN STEELS											
0.70	0.29	0.27	W 0.95	900	water	0.14	173	287	304	3.0	736
0.67	0.38	0.26	W 5.10	930	oil	0.13	170	284	307	3.5	736
0.67	0.38	0.26	W 5.10	1200	"	0.12	173	304	326	3.0	746
1.18	0.31	0.38	W 5.20	900	"	0.13	166	288	316	6.5	...
CHROMIUM STEELS											
0.98	0.65	0.32	Cr 1.60	900	oil	0.14	180	295	320	10.0	755
0.72	0.49	0.19	Cr 2.18	900	"	0.14	164	304	329	11.5	753
0.75	0.49	0.19	Cr 2.18	1100	"	0.15	171	305	351	5.0	760
0.71	0.34	0.37	Cr 4.88	900	"	0.14	...	660	694	0.8	787
0.53	0.70	0.44	Cr 6.59	900	"	0.15	...	645	674	0.5	805
1.14	0.32	0.25	Cr 15.0	900	"	0.15	...	596	627	0.5	816
1.14	0.32	0.25	Cr 15.0	1100	"	0.13	541	621	648	5.0	815
0.46	0.67	0.13	Cr 12.2	900	"	0.16	...	580	621	0.8	807
0.26	0.85	0.70	Cr 13.2	900	"	0.15	...	593	611	1.3	871
0.26	0.85	0.70	Cr 13.2	1100	"	0.16	415	607	624	2.5	879
VANADIUM STEEL											
0.79	0.23	0.28	Va 0.26	900	oil	0.13	176	280	306	6.5	743
MOLYBDENUM STEEL											
0.71	0.28	0.28	Mo 5.75	900	oil	0.14	174	289	312	4.0	737
CHROME NICKEL STEEL											
0.40	0.31	...	(Cr 1.00 (Ni 2.78	900	oil	0.15	184	294	317	4.5	721
CHROME TUNGSTEN STEEL											
0.41	0.24	...	(Cr 1.50 (W 1.58	900	oil	0.15	175	299	335	1.0	773
MANGANESE-VANADIUM STEEL											
0.78	1.74	0.47	Va 0.22	800	oil	0.10	177	303	332	17.0	729

slightly raised maximum and end. Silicon, on the other hand, reduces the intensity, but raises the maximum about 200 deg. C. for a silicon content of 2 or 3 per cent. Ac_1, however, is lowered by manganese and raised by silicon. Evidently it is essential that these elements be kept fairly constant in determining the influence of other alloy constituents.

Two per cent nickel and five per cent cobalt do not affect the maximum of Ac_t in a marked way. It is raised 5 to 10 deg. C. and the intensity is perhaps slightly reduced although Ac_1 is strongly lowered by nickel and raised by cobalt. Tungsten acts in the same manner on Ac_t and there is little difference between the result for 1 per cent or 5 per cent. Ac_1 is only slightly changed.

Chromium steels were studied in a little more detail than the others, seven compositions being run. These show a very significant phenomenon best brought out by plotting the data as in Fig. 2. With increasing chromium content (up to at least 2.2 per cent), Ac_t rises slowly. In the gap between 2.2 and 4.9 per cent chromium it rises abruptly, about 360 deg. C., after which it falls slightly with further increase in chromium content. The exact limits of composition between which it changes from the low to the high temperature range can not be settled because of the limitations in compositions available. It is, however, evident from similar data furnished by Edwards & Norbury[3] that the upper limit is below 3.9 per cent chromium. This result is particularly surprising since there is no corresponding break in the curve for Ac_1. It is quite possible that silicon shows a similar phenomenon, but a sufficient variety of silicon steels was not at hand to test this point.

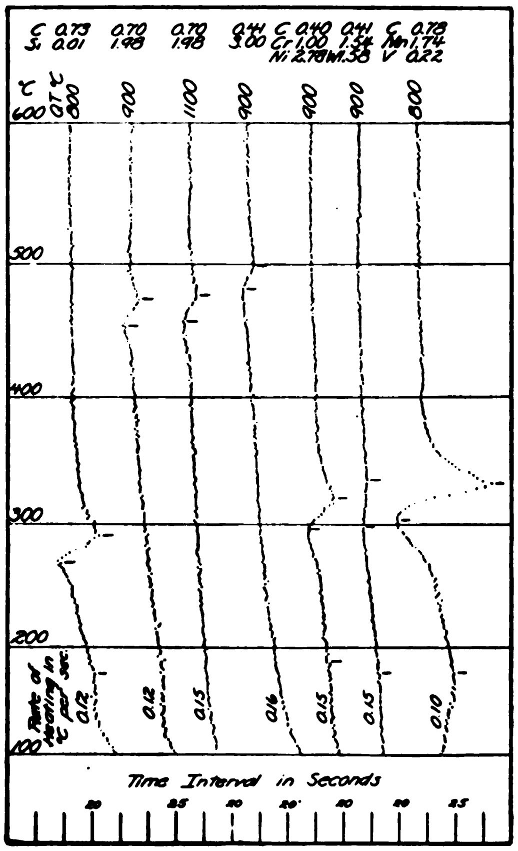

Fig. 1—Heating curves of some hardened alloy steels.

The vanadium steel and the molybdenum steel showed no markedly different characteristics from plain carbon steels except that both Ac_t and Ac_1 were raised somewhat. Combinations of two alloying elements in the three quaternary steels investigated chrome-nickel, chrome-tungsten and manganese-vanadium, acted as would be anticipated from the behavior of the individual elements.

Discussion of the Results.

There are a few general statements which might be made regarding the effect of the eight alloying elements considered. First, Ac_t substantially also raised Ac_1, but the converse is not true. The lack of a more general relationship is striking and evidence that an entirely different factor controls the precipitation of carbide at Ac_t from that at Ar_1.

Of the eight important alloying elements only three have a drastic effect on the heat evolution such as would be expected to be reflected in the technique of tempering. These are manganese, which increases the intensity, and silicon and chromium, which in certain percentages raise decidedly the temperature of Ac_t. It is therefore evident that the special properties conferred by the other elements are not due to variations in this transformation.

These facts suggest several observations regarding the tempering of alloy steels. If both manganese and carbon are high, as in some tool steels, and it is desired to temper well up in the Ac_t range, the steel should be heated very slowly to the temperature chosen, otherwise the large quantity of heat evolved may cause the temperature of the specimen to rise above that of the heating medium and so complete Ac_t. In this event the actual tempering would be higher than that indicated by the temperature aimed at. This is a highly undesirable possibility for the change in physical properties on passing from martensite to troostite is probably more pronounced than it is usually thought to be. It has evaded notice because of the lack of knowledge of the temperature range in which to look for it.

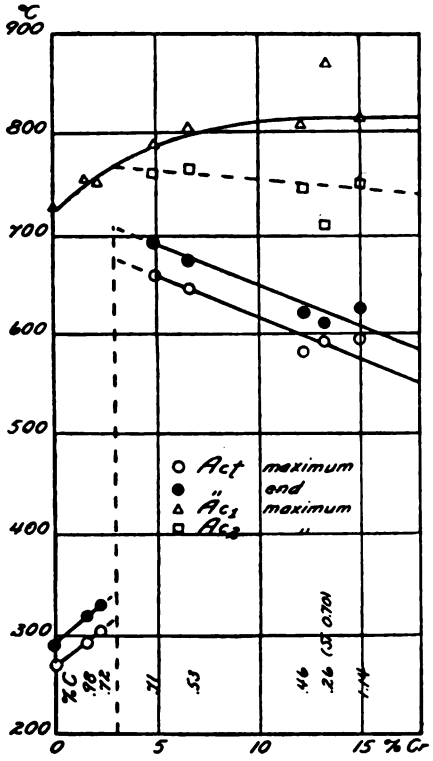

Fig. 2—Effect of chromium on the temperature of Ac_t, Ac_1 and Ac_3 in hardened chromium steels.

The steels with a high Ac_t have the interval between the end of Ac_t and beginning of Ac_1 shortened so that the troostite-sorbite tempering range is correspondingly reduced. The slope of the hardness-tempering temperature curve is thereby increased as shown by the curve for the silicon steel in Fig. 3. If commercial tempering is done in this range, the tempering temperature limits must be closer than in a steel of low Ac_t, in order to keep the hardness variations within the same limits. It is also evident from Fig. 3 that the other steels of this figure which have a low Ac_t soften at a lower temperature than does the silicon steel, but all of them have higher hardness when tempered to sorbite than the 0.70 per cent steel.

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[3] Edwards & Norbury; J. Iron & Steel Inst., 101; 447, (1920).

It has often been implied that the property of "red-hardness" in high-speed steel results from the ability of tungsten which is evidently a factor contributing to "red-hardness." If, however, the observation that Ac_t is not raised by 5 per cent tungsten also holds for higher contents, that can not be a valid explanation of the phenomenon. Referring to Honda and Murakami's magnetic curves,[4] which also reveal Ac_t, one finds that this change is raised only slightly by as much as 19.5 per cent tungsten, a degree quite insufficient to account for the resistance to tempering of high-speed steel. Evidently this characteristic property of high-speed steel is not conferred by tungsten, but by chromium, and the explanation of the function of tungsten must be sought along other lines.

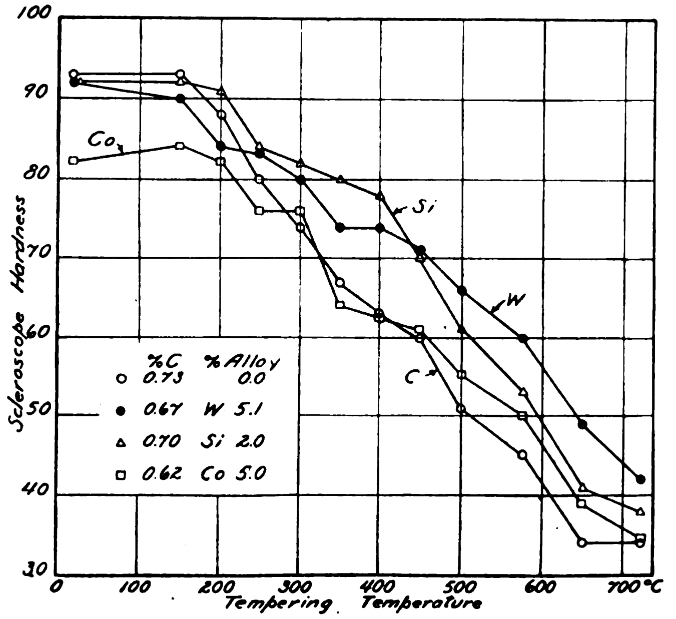

Fig. 3—Effect of tempering on the scleroscope hardness of carbon, tungsten, silicon and cobalt steels.

Thermal analysis, it is seen, offers a convenient method for determining the boundary between martensite and troostite of tempering which is a transition of considerable importance in the treatment of tool steel. It does not, however, give any indication of the change from troostite to sorbite which is of principal interest in the tempering of structural steels. A knowledge of the effect of alloys on this change is essential to a comprehensive analysis of the phenomena of tempering in alloy steels. The magnetic properties present a likely means for determining it accurately, but as yet few data are available. The comparison of alloy steels on the fundamental basis of constitution is dependent on such information.

Summary.

To summarize, it may be stated of the eight alloying elements manganese, silicon, nickel, cobalt, tungsten, chromium, vanadium and molybdenum, whose effect on the decomposition of martensite was studied by means of thermal analysis that only three, manganese, silicon and chromium, change the characteristics of the transition substantially. Of these, the last two raise the temperature of the transformation to a degree which may affect the tempering given to secure a predetermined constitution. In no case is Ac_t lowered. The two elements which raise Ac_t also raise Ac_1, but the latter not as much as the former, thereby shortening the troostite-sorbite tempering range. However, all elements which raise Ac_1 do not raise Ac_t. Hardness-tempering temperature curves show the effect of silicon in maintaining hardness for higher tempering temperatures than in carbon steel and that of tungsten, cobalt and silicon in increasing the hardness of highly tempered steel. It is shown that chromium and not tungsten is the element in high-speed steel which develops resistance to tempering.

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[4] Honda and Murakami: Sci. Reports Tohoku Imp. Univ., 6, 235, (1918).

ETCHING REAGENTS FOR ALLOY STEELS

Several series of "sequence etchings" have been tried out by the U. S. Bureau of Standards on a specimen of high-speed steel which was in the "as received from the mill" condition. Sequence etching means the etching with two or three reagents in successive order without any repolishing of the section between the etchings, and the taking of photomicrographs after each etching at the same spot in the microsection in order to note any changes in microstructure produced by the last etching as compared with that developed by the preceding etching reagent.

The reagents used in various combinations were: (1) Dilute ammonium hydroxide solution, together with a weak electric current, the specimen being made positive pole; (2) two per cent alcoholic solution of nitric acid; (3) boiling sodium picrate; and (4) Murakami's reagent (solution of potassium ferricyanide and sodium hydroxide) at boiling temperature.

The results, as judged from the behavior toward the various etching reagents tried, appear to show that there are at least three different constituents present among the imbedded globules or particles in the specimen of high-speed steel, in the "as received from the mill" condition, though any attempt to state the nature of these constituents would, in view of present developments, involve speculation.

DRILL STEEL SURVEY REPORT

The first progress report to members of the advisory board to the Bureau of Mines and the Bureau of Standards on the breakage and heat treatment of rock drill steels and other steels and alloys subjected to similar impact stresses has been made by Dr. H. Foster Bain, director Bureau of Mines, and Dr. S. W. Stratton, director Bureau of Standards, covering the work done in the month of April.

The survey was begun on April 1 with the object of determining the present status of the types and sizes of drills as related to the heat treatment and breakage of rock drill steels. During that month a large number of mines, largely copper, were visited by F. B. Foley and H. S. Burnholz, metallurgists Bureau of Standards. The report, which is a lengthy one, gives the practice of each mine as to the kind of bit, the size of steel and in some cases the heat treatment used. No conclusions are drawn or comments made.

Breakage of Rolls on Sheet and Tin Mills

General Discussion Giving the Cause For Rough Rolls On the Mills and the General Effect That They Have Upon the Product.

By W. H. MELANEY

PART III

ONE of the most annoying as well as costly conditions on Sheet or Tin Mills, is the roughing up of the chilled surface of the rolls during the rolling process. Especially is this true when making high grade sheets such as are used in the manufacture of automobiles, where an almost perfect surface on the sheet is required.

This roughing up can be divided into four classes, each one of which has its individual characteristics and is totally different from either of the other classes.

The first is the most prevalent one, the one that gives the most trouble and is known as gathering. The second is known as pitting. The third as simple roughness and the fourth as crazing or checking, because of the fine raised check lines in the form of squares left on the surface of the sheet.

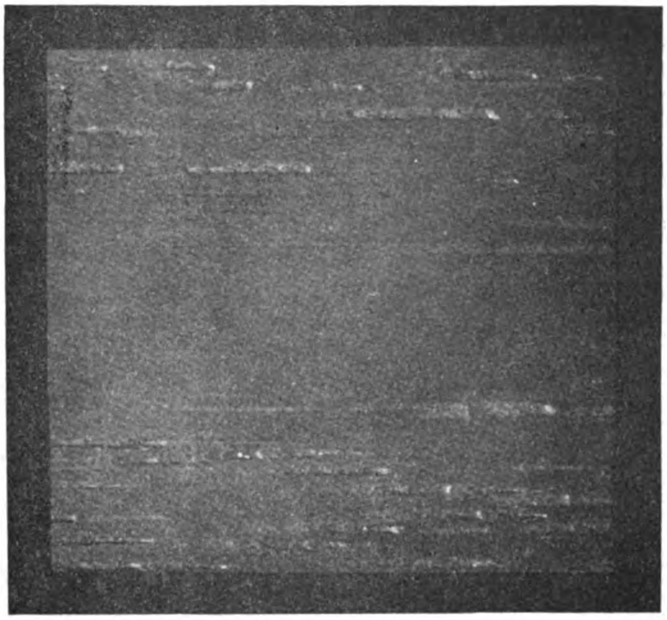

Fig. 1—Part of sheet showing the effects of gathering.

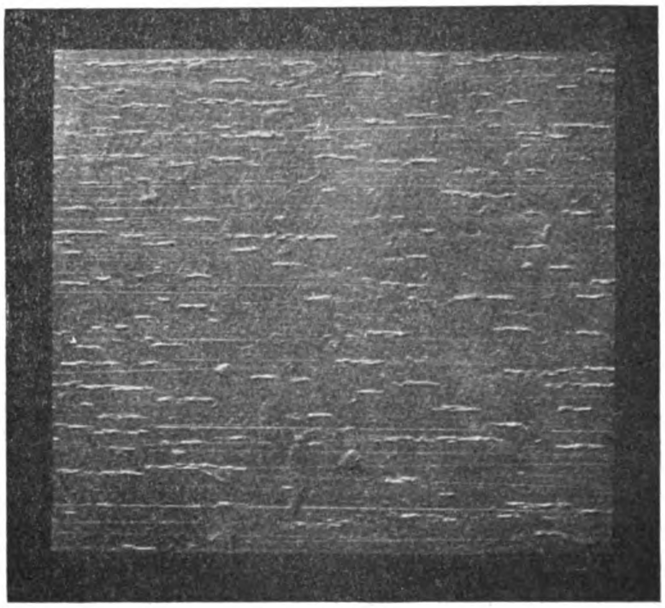

Fig. 2—Part of sheet showing the effect of pitting.

The roughing up of the surface of the rolls is most troublesome in the beginning of the week, because of the unfavorable conditions under which the rolls are then operating and will be discussed later on under the proper heading. Roughing up is not to be confused with bad surface on the sheets, due to scale or other impurities in the sheet bar, being rolled into the face of the sheet, nor with any imperfections caused by deposits of ash or other products of combustion left on the sheets by the furnaces.

In dealing with roughness, the first thing to be considered is to which class it belongs, as the remedy will be different in each case.

Gathering.

Gathering is that form of roughness where the face of the roll becomes covered in certain well defined bands, by small particles of extremely hard substance, evidently steel built up on the face of the rolls, standing out in relief and which due to the pressure and the revolving of the rolls, are finally elongated or stretched into streaks or lines in the direction of the rolls.

These lines being in relief cut into the face of the sheet and produce indentations that are impossible to remove by any amount of cold rolling and in the case of very thin sheets, cut completely through the surface sheets of the pack. This is why this form of roughness is the most objectionable, as the effect once produced on the sheet it is impossible to remove it by any future treatment. See Fig. 1.

Cause of Gathering.

There are a number of causes for gathering, several of which may exist at the same time.

An extremely mild chill roll is more susceptible to gathering than a harder one, because the more open the structure of the metal composing the face of the roll, the more readily the small particles will build up on its face. The primary cause of gathering, however, is one of friction and can be produced in various ways.

When two sheet or tin rolls run together after being heated up, as the top roll is driven by friction from the bottom roll, there will always be some slight slippage or lagging of the top roll, due to difference in neck lubrication, or the rolls being slightly crossed, that is, out of perfect alignment with each other, or perhaps too tight lining up of the side brasses or not enough end play, thus causing a variation in the friction load of the top roll. This results in friction between the surfaces of top and bottom rolls, because the rolls are hot and of course unlubricated and small particles of metal are torn out of the face of the rolls, where the two surfaces touch, and also out of the surface of the pack or sheet bar.

These particles, due to the pressure of the top roll upon the bottom one, adhere to one or both rolls and gradually build up under pressure and elongate in the direction of the rotation of the rolls until these gathered particles form a pronounced ridge or projection upon the face of the roll, which requires frequent scouring with a carborundum block to remove.

This, as will be noticed, forms most readily on that portion of the roll's face where narrow bearings occur, as the roughness of these bearings offer more favorable conditions for the building up of these small particles of steel and when they appear, they must be removed by scouring the surface of the roll with a coarse carborundum block, which cuts away these projections and leaves the surface of the rolls smooth again.

The purer the steel in the bar or pack, that is being rolled, that is the lower the sulphur and phosphorus content, the more the trouble that will be experienced from gathering. This is due to the fact that the small particles of steel torn out of the face of the bar, will weld up under pressure, much more readily when pure than when the phosphorus and sulphur content is higher.

Also, bars heated with gas give more trouble from gathering than those heated with coal, because the sulphur in the coal produces a sulphur oxide on the face of the bar, which being only skin deep, does not effect the interior of the bar, therefore, is not deleterious to the quality of the sheets and is not objectionable.

For the same reason, pickled bars give more trouble from gathering because all the scale has been removed, leaving pure particles of steel to be torn from the pack which weld up readily under the pressure of the screws of the mill. This is the reason that gathering is more apparent when too much screw is used on bar or packs, as the greater screw pressure produces a better welding condition.

Gathering occurs most in the fore part of the week, because the condition of the face of the rolls at this time is most favorable to gathering.

This is caused by the turning or dressing of the rolls in the roll lathe, as the dressing off of the rolling face of a chilled roll is decidedly a scraping rather than a cutting process and this opens up the grain of the chill and leaves an open texture that the small particles of steel readily adhere to.

After the rolls have been run long enough to close up their face, due to the pressure of the two rolling surfaces upon each other, gathering is not so apt to appear as the hardened surface will not permit the particles of steel to adhere.

Pitting of Rolls

The pitting of rolls is a different type of roughness and results from several causes, but is not as serious as gathering, because in this case the pitting, as the name implies, leaves small depressions in the face of the roll, which in turn leave projections on the sheet which are easily removed by the cold rolls. See Fig. 2.

The worst form of pitting is caused primarily by the gathering being permitted to remain on the race of the roll too long before it is scoured off. The result is the elongated ridges built up on the face of the roll and which are harder than the roll face and due to the pressure of the rolls upon each other, these ridges are sunk partly into the face of the roll and when the ridges are scoured off they leave underneath these ridges, a depression in the face of the roll, corresponding in size and shape, to the ridges that produced them, so that the sheet looks much the same as it did under gathering except that instead of leaving indentations in the face of the pack, which would ruin it, they are now small projections similar in shape and size, to the original ridges that produced them, and which can be rolled down on the cold rolls but do not make a perfect finish on the sheet.

Another form of pitting is due to small particles of scale torn from the bars and packs being rolled into the face of the rolls, forming small irregular indentations which leave projections on the face of the pack. They, of course, are removed by the cold rolls and while not desirable, are not so serious as other forms of roughness and can be more readily removed by the scouring block.

Rough Surface.

This type of roughness usually appears in streaks or bands around the circumference of the rolls and is caused by narrow bearings where the surfaces of the top and bottom rolls come in contact with each other, and the slippage of one roll upon the other roughens up the surface very rapidly after the rolls become heated and this would happen, even though no metal was being rolled.

This type of roughness results generally, either from uneven expansion of the rolls, or uneven polishing, and under this condition, is more or less under control of the roller, but it can also be caused by careless roll turning and when this is true, the only solution is to re-dress the rolls.

Another condition that sometimes happens when newly dressed rolls are put into service, is polished streaks on the surface of the sheets and is caused by exactly the same conditions as noted above, that is, the rolls only touch in streaks and this closes up the grain of the chilled surface on these narrow bearings, which had been opened up by dressing.

The surface of the roll at these places becomes denser, due to compression, and leaves a polished streak upon the sheet, but if allowed to continue without acouring off, they will eventually develop into rough streaks.

Crazing of Rolls.

Crazing of rolls is not a very serious condition usually, as its effect on the sheets can be removed by the cold rolls.

By crazing is meant the finely checked or grained surface of the roll, leaving a fine hair line in relief all over the surface of the sheet, crossed at right angles by other hair lines forming fine squares or checks all over the surface. If you examine the rolling surface of the rolls closely, you will find it all broken up into squares (giving it a grain-like effect) by fine cracks no larger than a hair. These leave the lines in relief on the sheets and can be removed by the cold rolls with no apparent bad effect except when the squares are so large as to be plainly noticeable on high grade surfaces, such as automobile sheets, and this sometimes happens.

This crazing is caused by the rapid expansion of the chilled surface of the rolls, both longitudally and circumferentially, really tearing the skin of the surface apart and the slower the rolls are warmed up the finer will be the checks and when the squares become large enough to be objectionable, it is an indication that the rolls were too rapidly brought up to working temperature and the roll in expanding started to tear its surface apart as chill, like glass, is of a crystalline structure and very sensitive to heat conditions. It is obvious that the way to avoid this condition is slower warming up.

You will also note that when the rolls are gagged or in any other way stopped with a hot bar or pack between them, that these squares on the surface of the roll at the point of contact with the hot bar are very much enlarged, due to the rapid heating of the surface of the roll and when this happens, a condition is started in the roll that will ultimately cause it to break, as it is already badly ruptured on its surface and these cracks extend practically through the chill.

Spawls

This is also one of the causes for rolls spawling, although the spawl does not usually occur until later on and this is the reason the statement is so often made, that the roll spawled without apparent cause as the cause may have happened long enough ago to be overlooked.

Another cause for spawls, of course, is a crush, due to rolling a pair of tongs or a cold black end, and as stated above, does not occur until later on, when the cause has been forgotten.

This is the reason a roll manufacturer will not replace a spawled roll, as it is purely a mill condition and not an inherent defect in the roll itself.

Combustibility of Blast Furnace Fuels

The Influence of Structure On the Combustibility and Other Properties of Solid Fuels Used In Steel Works.

By E. R. SUTCLIFFE and EDGAR C. EVANS

THE influence of structure on the combustibility of fuels is a subject which has received very little attention. The most systematic work on the subject has been in connection with fuels for blast furnace purposes, chiefly between 1884 and 1890, and this work still retains a considerable interest.

Thörner made a most interesting investigation in 1885 on the structure of blast furnace steels (Stahl und Eisen, 1886, 6, 71). His memoir was accompanied by some very instructive photomicrographs of sections of coke and charcoal. He found that the fuels which gave the best results in the blast furnace, viz., Meiler coke and charcoal, were characterized by high combustibility, high degree of porosity, and comparatively high percentage of volatile matter, and that they contained pores, the cell walls of which were either longitudinal in direction or had a pronounced tendency in that direction. He quotes his results as being in agreement with those of Belani and Kutscher, who from practical experience had come to the conclusion that the ideal furnace coke should be "as voluminous, as rich in pores, and as similar to charcoal as possible."

Later Belani (Stahl und Eisen, 1885, 5, 603) suggested that the heating value of a fuel per unit of time depended on the combustibility of the fuel and on the amount of surface presented to the draught. He found that the (surface of charcoal): (surface of coke) = 5.5:1 and the (combustibility of charcoal): (combustibility of coke = 1.5:1, from which he calculated that the ratio of the heating power of charcoal per unit of time to the heating power of coke per unit of time is 5.5 × 1.5 = 8.25:1.

Very little work has been done in England on the influence of structure on the properties of fuels, probably because of the fact that the use of charcoal in metallurgical operations had been discontinued in England long before blast furnace technology had reached the level of an exact science.

Even Bell, in his monumental work on the blast furnace, had to depend for his knowledge of charcoal as a fuel, almost entirely upon the evidence submitted from abroad, and the question of "combustibility" as apart from "heating value" plays therefore very little part in his calculations.

Armstrong, however, in his paper on the "Mechanics of Fire" (J., 1905, 473), pointed out in a footnote the important possibilities of changes which constitute the process of combustion, while Bone's work on surface combustion emphasized in a remarkable way the importance of structure in the combustion of gases on an incandescent surface.

At present, while it is realized that structure does play a part and an important part in the combustion of coal and other solid fuels, the complexity of the combustion phenomena in the case of non-carbonized fuels has made it extremely difficult to determine the nature and extent of its influence, while in the case of carbonized fuels—particularly gas coke and furnace coke—the phenomena of combustion are also complicated by the refractory character of the graphitic skin of carbon which is formed during most processes of high temperature carbonization.

The possibilities of structure in the combustion of solid fuels were brought home to the authors in a rather interesting manner in connection with a mine fire in South Wales. The fire had been burning for several

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Abstract of paper read by authors before Society of Chemical Industry Burlington House, April 3, 1922.

months, and to prevent it spreading, the fire zone had been totally enclosed by brick stoppings, while further, very considerable quantities of carbon dioxide had been injected into this screen (vide Proc. Inst. Mn. Eng., V., 51, 209). By this means it had been found possible to reduce the oxygen percentage to 1.5—3.0 per cent, but even this small proportion proved sufficient to maintain slow combustion, and it was ultimately decided to quench out the fire. For this purpose one of the brick stoppings was removed. The effect of increasing the oxygen percentage on the burning coal was extremely interesting. When first viewed through the open stopping the face of the seam was black; the slow combustion that was taking place was not sufficient to raise the temperature to the ignition point, but as the increased percentage of oxygen began to exert its influence active combustion started. It did not, however, commence at one point, but started at a number of points entirely isolated and independent of one another, making the coal seam appear like a number of stars. Combustion did not spread from these, but the stars simply multiplied, breaking out one after another independently until finally the whole seam was covered, and appeared to be a red burning mass.

Even at that time the phenomena observed seemed apparenty to be due to surface combustion at points where conditions were favorable. The illustration is of some interest in view of recent work, and has a significant bearing on some of the views advanced later.

When the question of combustion of coal is studied in detail, the problem is very seriously complicated by the heterogeneous character of coal. A number of observers have studied the question of the ignition temperature of coal. Tables of ignition temperatures are frequently published which show a gradual increase on passing from bituminous coal to anthracite, but these tables after all simply give the temperature at which the gases evolved from the coal ignite, and these temperatures vary not only with the coal, but with the different constituents of coal itself.

The constitution of coal has been studied by a number of observers, and notably by Wheeler and his collaborators, and the essential difference between various coals can easily be realized by a study of photomicrographs of coal sections. But while these photographs show clearly the internal structure of coal, while they show the heterogeneous character of most coals, and explain the difference in ignition temperatures of various coals, they do not themselves explain the very considerable differences in combustibility. Some coals are said to be "bright" and "active" in combustion, others again of similar content of volatile matter are said by stokers to be "dead" in burning. The reason for this is not entirely due to composition or constitution; it is a matter in which the structure of the carbonaceous residue left after the volatile products have been burned off plays an extremely important part.

In examining the question it is advisable at the outset to simplify the investigation by studying the behavior of coals which neither fuse nor decrepitate in the furnace. Highly fusible resinous coals which cake together in a grate or in a boiler furnace form a semi-caked mass which has to be poked and stirred frequently to allow of the free passage of air and heated gases through it.

Other coals decrepitate and fall to pieces, leaving a dust which impedes the action of the air blast, and to avoid complicating the field of study it is advisable to eliminate both these classes, and to select coals which burn easily and steadily without necessity for excessive poking. South Wales steam coals offer excellent possibilities in this direction, while high volatile non-caking coals can also be studied to advantage.

The combustibility of a fuel of this type may perhaps be defined as the ease with which it combines with oxygen. This involves the time factor. The rapidity with which a fuel burns may be taken as a criterion of its combustibility. It is not a question of calorific value. Two different fuels may have the same calorific value, but one may burn much more easily and much more quickly than the second, and the consumption per square foot of grate area per unit of time may be considerably greater. The temperature attained by combustion may also be higher. As an extreme example, the old textbook illustration of the rusting of iron may be quoted. The heat units produced might be the same as if it burned in oxygen, but the temperature attained is very different in the two cases.*

A method that has been used in determining the combustibility of a carbonized fuel is to note the effect of air and of carbon dioxide upon the fuel at various temperatures, and to note the loss of weight in successive periods of time (Thörner, *loc. cit.*, and Bell, "Principles"). By this means it has been found that the porosity of a fuel plays an extremely important part in determining its combustibility.

In studying on a large scale the factors that play a part in determining the combustibility of a fuel, the first step is to obtain a homogeneous product. At the outset it will be noticed that homogeneity itself, apart from other factors, exerts an important influence.

Homogeneity of Size.

The first attempts to obtain a homogeneous fuel commercially have been in the direction of sizing the coal. Sizing non-caking steam coals, anthracite coals, and some American high volatile coals (*e.g.*, Illinois coals) has proved of considerable advantage for steam raising purposes.

In so far as American anthracite is concerned, sizing has been absolutely necessary for the following reasons (Cullon, "Cours d'Exploitation des Mines Texte," III., 183). (1) Pennsylvania anthracite will not decrepitate in the fire to burn without sizing. (2) If in too large size the cold mass will be in too great proportion to the incandescent surface. (3) The sizes should be the same so that all particles should be under the action of flame at the same time. (4) Small particles should not be so numerous as to fill up the spaces between the large particles, and thus impede the passage of the air and heated gases.

In the case of non-caking bituminous coals, the following advantages are claimed for sizing (Malcolmson, First Annual Convention Int. Railway Fuel Assoc., 1909). (1) Increase of fuel and boiler efficiency. (2) Less loss of fuel in ash. (3) Less smoke. (4) Uniform combustion insuring greater capacity of furnace. (5) Less draught needed. (6) Longer life of grate. (7) Furnace under better control. Steam can be raised more rapidly. (8) Less danger of spontaneous combustion of stored coal.

The claim for increased furnace efficiency has not been confirmed in detailed tests made by the U. S. Bureau of Mines, but the other advantages are generally acknowledged, and the large market that exists for sized

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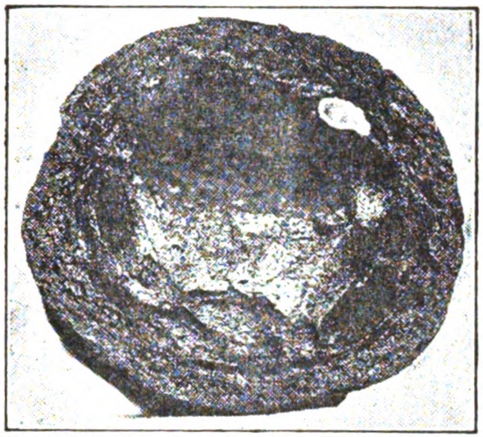
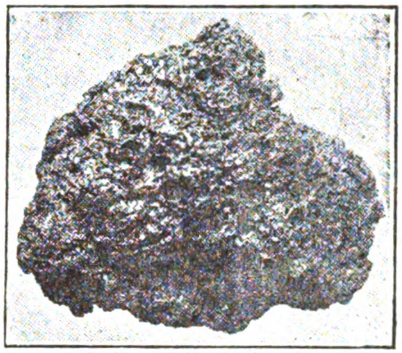
*This illustration is, of course, not strictly correct, as the oxides are different.



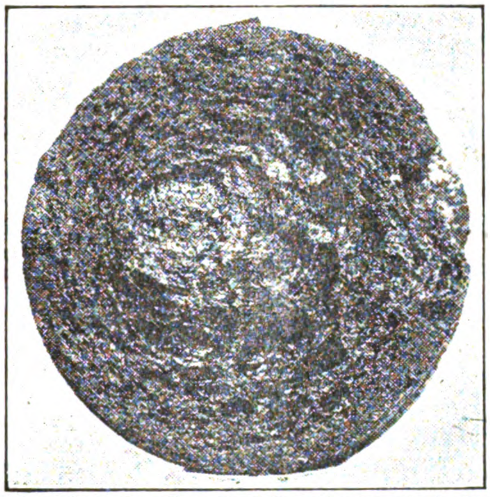
Low-temperature coke.—From No. 2 Rhondda coal. Natural size.

Fig. 1.



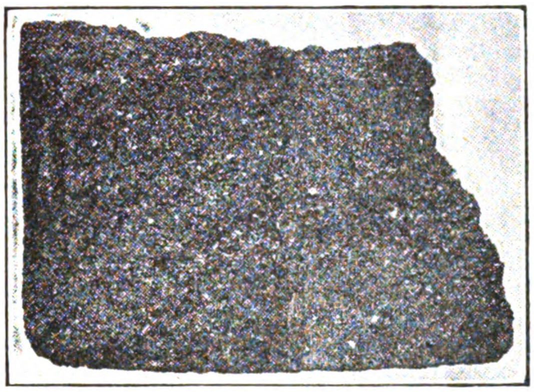
Coalite. Half natural size.

Fig. 4.



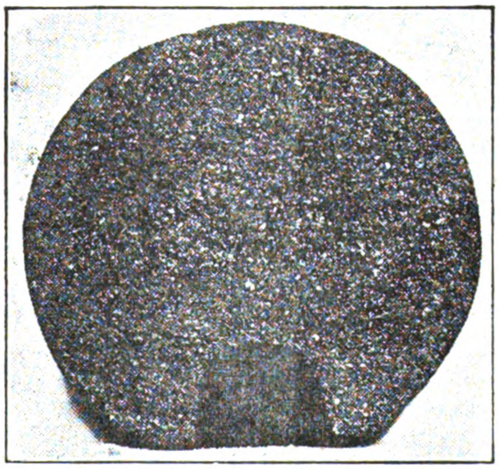
Low-temperature coke.—From No. 2 Rhondda coal, mixed with a proportion of coke breeze. Natural size.

Fig. 2.



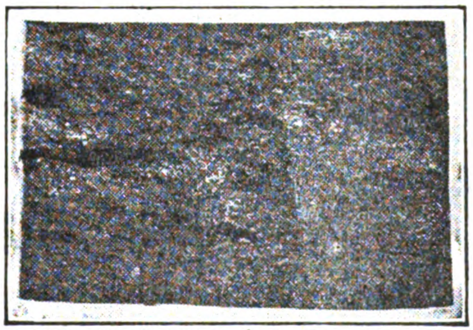
South Metropolitan smokeless fuel. Natural size

Fig. 5.



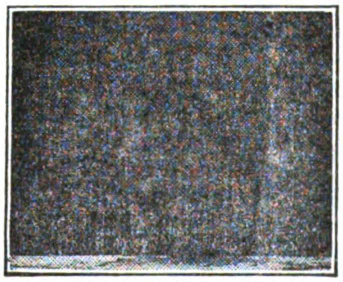
Low-temperature coke.—From No. 2 Rhondda coal, mixed with a proportion of preheated coal. Natural size.

Fig. 3.



Pure coal briquette—Carbonised—South Wales steam coal. (No addition of coke.) Natural size.

Fig. 6.



Pure coal briquette—Carbonised—(Lancashire coal mixed with 25% coke breeze.) Natural size.

Fig. 7.

coal proves that it has many important advantages in large-scale work.

Influence of Dimensions of Fuel Particles.

Ceteris paribus, the smaller the particles of coal, the greater the combustibility. This, of course, arises from the fact that the surface area increases considerably in proportion to the bulk as the diameter decreases. This principle is applied in using anthracite for raising steam.

Anthracite is by no means a fuel of high combustibilty, and is extremely difficult to burn in an ordinary boiler furnace if in large sizes. Yet anthracite peas carefully sized make an ideal boiler fuel and have better steam-raising qualites than even high-class Welsh steam coals.

The ultimate possibilities in this direction are obtained in the case of powdered fuel. The extremely high degree of combustibility of coal dust in a fine state of subdivision has long been realized in connection with the study of mine explosions, and the same principles which make coal dust such an explosive agent, are now made use of commercially in many applications of powdered fuel.

Powdered fuel, however, is by no means an ideal material. It cannot be stored, it cannot be transported *per se,* and is liable to spontaneous combustion. For this reason attempts have been made, as in the colloidal fuel process, to make it transportable in the form of an emulsion of oil and coal. There is, however, a method of retaining to some extent the highly combustible extremely active properties of powdered fuel, and at the same time make it easily transportable, and that is to briquette it.

Homogeneity of Size and Structure.

It is perhaps an euphemism to regard patent fuel briquettes, as customarily made, as consisting of powdered coal.

The advantages of fine grinding prior to briquetting have long been known to the briquetting industry. It increases the combustibility of the briquettes, and improves their appearance, but on the other hand finely ground coals require a greater percentage of binder than coarsely ground material, and as a rule, if made by the ordinary process with pitch as a binder, the briquettes are rather weaker. In practice, therefore, a compromise is effected, and the coal is only ground to the extent that would be effected by an ordinary Carr's disintegrator. Even so, briquettes made with pitch possess many advantages over coal, and these have been summarized as follows (*vide* Malcolmson, "Commercial Aspects of the Coal Briquetting Industry," Trans. 8th Int. Cong. Appl. Chem., Vol. 25). (1) Briquettes can be readily transported and handled and stored for an indefinite period without deterioration. (2) Briquettes when burned in locomotives under standard conditions show an increased boiler efficiency over coal of the same calorific value amounting to 15 per cent in favor of the briquettes. (3) It has been demonstrated that 25 per cent more briquettes than coal can be burned per sq. ft. of grate area per hour.

In other words, briquettes are more combustible than raw coal, a result entirely due to the difference in structure between briquettes and coal.

The principal advantages of briquettes can ultimately be attributed to their homogeneity both in respect to structure and to the size of the particles of which they are constituted.

Briquettes made with pitch in the usual way are not entirely homogeneous. The coarsely ground coal of which they are made is not uniform in size and the addition of pitch introduces a further complication.

A stage further in the direction of homogeneity can, however, be attained by making briquettes without the addition of binding material, the briquettes thus consisting of uniformly sized particles of the raw coal itself cemented together by the binding material in the coal substance. Briquettes of this type can be obtained by finely grinding the coal and subjecting it under suitable conditions to a pressure of about 10 tons per sq. in. For all practical purposes briquettes of this type can be regarded as solidified coal dust; they are considerably more homogeneous in structure and constitution than any of the fuels yet dealt with, and a study of their properties serves to illustrate in many ways the effect of structure on the general properties of fuels.

The combustion of these briquettes in a domestic grate proceeds with much greater regularity and uniformity than that of raw coal and presents the following special features: (1) After the volatile matter has been burned away the briquettes burn easily and steadily in a similar manner to charcoal. (2) They remain ignited until practically the whole of the carbonaceous matter has burned away, leaving no clinker, but only a residue of finely divided ash. (3) The radiant heat emitted from a fire of these briquettes is considerably greater than that from a coal fire.

The following comparative test made with a raw coal of volatile matter 35 per cent, ash 5.6 per cent, and briquettes from the same coal made without a binder may serve to illustrate the difference between the combustion of briquettes and raw coal:

	House coal	Briquettes
Weight taken	6 lbs.	6 lbs.
Time taken in burning	6¾ hrs.	9½ hrs.
Unburned cinders	20½ oz.	1 oz.

The unburned cinders from the briquettes were found in the extreme corners of the grate. The material in the center had burned completely away.

The proportion of unburned cinders left in both cases is significant. A coal fire goes out because the heat generated at the incandescent surface becomes too low to raise the temperature of the cold mass to the point of ignition. If, however, the area of the incandescent surface is increased, or alternatively, if the temperature of the unburned mass becomes raised during the combustion process, combustion will proceed.

Despite the fact therefore that the period of burning of the briquettes was longer than that of the coal, their combustibility was considerably greater.

The fact is brought out by a series of comparative boiler trials made at the South Wales School of Mines on raw coal, briquettes made from the same coal with pitch as a binder, and briquettes from the same coal made without a binder. In a series of preliminary laboratory tests it was noticed that briquettes made without a binder when burned in a bomb calorimeter burned with a rapidity far greater than that of either raw coal or briquettes made with pitch, the period of combustion being very often 30 per cent less than that of coal. This increased combustibility is shown with still greater clearness in the series of tests summarized in Table I.

These tests are imperfect in several respects; the boiler efficiency was low (as would naturally be expected in the case of hand-fired experimental boiler installation) and in many respects they failed to bring out to the best advantage the superiority of the briquetted fuels. Still the following points may be noted:

1. The heat transmitted per sq. ft. of heating surface per hour was 4070, 4039, and 4650 Btu. respectively.
2. The weights of dried fuel burned per sq. ft. of grate area per hour were 13.78, 15.05 and 16.4 lbs., respectively.
3. The equivalent evaporations per lb. of carbon value from and at 212 deg. F. were 7.31, 7.31 and 7.35 lbs., respectively.

4. A constant draught of 0.6 in. was maintained in each case, and a uniform rate of feeding the coal was adopted in each case. The briquettes made without a binder, however, burned away so quickly that with the thin fires maintained it was found very difficult to keep the grate fully covered at the end of the charging period. The efficiency therefore was reduced, and a better result could have been obtained either by reducing the draught or by working the boiler at a higher capacity.

Table I—Summary of comparative tests made at the South Wales School of Mines.

Fuel	Raw coal	Briquettes made with pitch	Pure coal briquettes
	Pct.	Pct.	Pct.
Ultimate analysis			
Carbon	86.3	82.3	82.1
Hydrogen	4.3	4.0	4.1
Ash	4.2	8.30	7.71
Sulphur	0.95	0.98	1.15
Oxygen Nitrogen	4.2	4.42	4.94
Moisture in coal	0.77	1.6	0.85
Analysis of boiler ash			
Moisture	2.37	0.23	0.85
Ash	51.80	63.25	34.25
Carbonaceous matter	45.83	36.52	64.9
Flue gas analysis			
Carbon dioxide	5.04	5.2	5.9
Carbon monoxide	nil	nil	nil
Oxygen	15.00	15.00	14.5
Nitrogen	79.96	79.80	79.6
Heat transferred to water per lb. of dried coal, Btu.	7426	6550.4	6997
Lower value. Calorific value of dried coal, Btu.	14,781	14,182	13,937
Heat transmitted per sq. ft. of heating surface per hour	4070	4039	4650
Weight of dried fuel fired per sq. ft. of grate area per hour, lb.	13.78	15.05	16.3
Equivalent evaporation of water from and at 212 deg. F. per lb. of dried fuel, lb.	7.52	6.85	7.25
Weight of feed from and at 212 deg. F. per sq. ft. of heating surface per hour, lb.	4.225	4.225	4.81
Equivalent evaporation per lb. of carbon value of fuel, from and at 212 deg. F., lb.	7.31	7.31	7.55

The results, however, are sufficient to show that the combustibility of briquetted fuel increased with the degree of fineness of the coal and with the homogeneity of the product.

The Combustibility of Natural Fuels—Summary.

In so far as natural fuels are concerned, the conclusions derived from the preceding notes may be summarized as follows:

1. Uniformity of size allows of an increased quantity of fuel being burned per unit of time per sq. ft. of grate area.

2. Briquettes burn at a faster rate than coal under equivalent conditions.

3. Fine grinding of coal for briquetting purposes increases the combustibility of the resulting product.

4. Briquettes made without a binder are more combustible than those made with a binder.

It seems evident from a consideration of the properties of briquetted fuel that structure plays an important part in determining their combustibility. The secondary reactions resulting from the presence of volatile matter make it difficult, however, to determine the nature and extent of its influence, and definite conclusions on the subject can only be come to after an examination of fuels which do not contain any volatile matter, *i. e.*, carbonized fuels.

Factors Influencing the Combustibility of Carbonized Fuels.

A very brief study of carbonized fuels is sufficient to show that the factors which determine their combustibility are more numerous and complex in character than is generally realized. The character of the fuel carbonized, temperature of carbonization, the rate of carbonization, and even the pressure under which the heating is effected, all play a part in determining the character and the combustibility of the resulting carbonized fuel. The effect of these various influences may be summarized as follows:

Influence of Character of Fuel Carbonized.

From the point of view of coke production, fuels can be roughly classified as fusible and non-fusible fuels. Fusible coals yield a coke which retains no trace of the shape and structure of the original coal. Non-fusible coals, on the other hand, yield a coke which approximates in shape to the original coal, and retains to a great extent its structure. (Charcoal can be quoted as an extreme example, as it has the cell structure of the wood from which it is produced. (See Figs. 12 and 13.)

Generally speaking, non-fusible fuels give a more combustible coke than do fusible fuels when carbonized under similar conditions.

Influence of Conditions of Carbonization.

This, however, is only a rough generalization, as conditions of carbonization play an extremely important part in determining the character of the fuel produced. Thus, to take an extreme case—by carbonizing wood under pressure a coke (not charcoal) can be obtained which retains no vestige of the original structure of the wood. But even under standard pressure, variations in the conditions of carbonization result in remarkable differences in the character and combustibility of the coke, and in this direction the two most important influences apart from the type of fuel used are the temperature and period of carbonization.

Effect of Temperature of Carbonization.

At first sight temperature might seem to be a factor of supreme importance in so far as the character and combustibility of a coke are concerned. Low temperature coke is much more free burning than high temperature coke, and it is generally assumed that the combustibility of the former is directly due to the volatile matter left in it by the use of a comparatively low carbonizing temperature.

A little consideration will show, however, that temperature is really not so important as it is generally considered to be. Cokes made at comparatively high temperature from splint or other non-fusible coals are comparatively free burning, while the authors, by carbonizing even fusible coals very slowly under suitable conditions, have succeeded in obtaining at high temperatures a fuel the combustibility of which is equal to that of any fuel they ever tested (*cf. infra*).

In the authors' opinion, temperature plays only a secondary part. The combustibility of low temperature coke is not due to the volatile matter, but to its structure. Many dry steam coals and also anthracites contain a volatile content of the same order as that of low temperature coke, but their combustibility in an open grate is very much lower. An examination of low temperature coke shows that it consists of a sponge-like mass with relatively thick cell walls. In the process of combustion the volatile matter in these walls is expelled. No fusion occurs, however, as the fusible constituents have been eliminated in the carbonizing process, and the expulsion of the volatile matter leaves a wall permeated with minute pores which enormously increase the surface exposed to the oxidizing gases and thus increase the combustibility.

In normal high temperature carbonization of a fusible coal the resinous constituents in the coal melt below the decomposing point, resulting in the formation of a thick viscid mass. As the temperature increases beyond the decomposition point, gas is evolved which blows the semi-liquid mass into a series of bubbles which run into one another and the ultimate result when the coke is "set" is the sponge structure referred to. A considerable portion of volatile matter is still left in the cell walls, however, and during the subsequent heating this has to penetrate to a great extent through a red hot mass of coke, and in its passage the hydrocarbons become decomposed, resulting in the deposition of graphitic carbon in the minute pores of the cell walls. Owing to the filling up of these pores the cell walls become more or less vitrified and are rendered impermeable to gases. The highly refractory incombustible character of high temperature coke is, in the authors' opinion, due to a great extent not to the low percentage of volatile matter, but to the non-porous character of the cell walls.

Effect of Period of Carbonization.

It is well known that the more rapidly a coal is carbonized at high temperatures, the more pronounced is the silvery-gray graphitic film referred to, while, on the other hand, if the coal is only gradually heated to the maximum temperature (as, for example, in a continuous vertical retort) the coke is less lustrous in appearance and more readily combustible.

If coal is uniformly heated, as, for example, in an internally heated retort, so that the center of the charge is at the same temperature as the portion nearest the walls, the secondary products of decomposition, instead of passing through a coked charge of continuously increasing temperature as in the case of high temperature carbonization, pass through zones of continually falling temperature and the secondary decomposition of the hydrocarbons on the minute pores of the coked material is therefore considerably reduced. The more slowly the charge is carbonized the slower is the evolution of the volatile matter and the more easily can it get away without being "cracked" or decomposed in its passage.

The ease of escape of the volatile matter is a factor of vital importance in determining the combustibility of the coke. Slow carbonization assists this in two ways: (1) As above by expelling the volatile matter so slowly that it can get away as it is formed, and (2) by converting a part of the fusible material of the coal substance into an infusible material. This, of course, facilitates considerably the ready escape of volatile matter.

The following experiment illustrates in an interesting manner the effect of a prolonged carbonizing period. A finely ground coking coal was briquetted without a binder, and the briquettes passed through an internally heated retort. Heating took place so slowly that a period of 72 hours was taken in bringing the charge to its maximum temperature of 1,000 deg. C. The briquettes retained their shape, but contracted during the process until the coke had a sp. gr. of 1.2, its structure consisting of a large number of minute cells with thin walls. The combustibility of this fuel was of the same order as that of charcoal. When once thoroughly ignited, a lump of this fuel could be removed from the fire, and if protected from draughts would continue to burn for several hours. In one test made a piece of a size 3 in. by 2 in. by 1½ in. made red hot and placed on a fireclay slab away from the fire, burned for over six hours until all that remained was a small piece 1x½x½ in.

Influence of Preliminary Treatment of Coal.

A very prolonged carbonizing period is, of course, not easy to reconcile with economic requirements on a commercial scale, but several methods are available which allow of the ready escape of the volatile matter. It can be done by (1) blending coal with coke breeze (Fig. 2), (2) blending caking with non-caking coals, or (3) preheating a portion of the coal to eliminate the resinous matter and mixing the resulting material in the correct proportions with raw coal.

All three of the above methods have been used by the authors in their works for several years, and similar processes have been worked out independently by other investigators, more especially by the Fuel Research Board, by Roberts (Trans. Inst. Min. Eng., 62, 9), and by Illingworth (Proc. S. W. Inst. of Engineers, 1921).

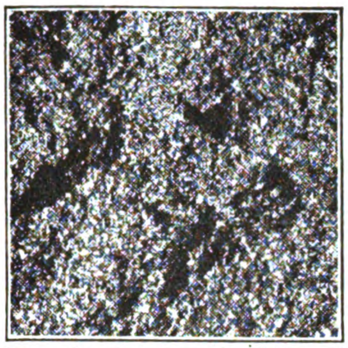
Mr. E. V. Evans and his collaborators of the South Metropolitan Gas Company have also worked out on a small commercial scale a process on similar lines. In this process, ground coke breeze and a cheap coal are mixed in such proportions that sufficient binding material is subsequently obtained from the coal. The mixture is afterwards carbonized at such a temperature that a compact mass results from the shrinkage that occurs, the temperature usually adopted being that of waste furnace gases—about 500-550 deg. C. The resulting product is hard and dense. It is an excellent smokeless fuel and is capable of withstanding the most severe conditions of handling and transport.

In order primarily to meet the economic requirements in large scale production of smokeless fuel, the authors have developed a method of preliminary briquetting of coal without a binder, and subsequent carbonization of the briquettes. In the case of most British coals swelling of the briquettes during carbonization can be prevented by the addition of 20 to 30 per cent of previously carbonized material to the coal, but in the case of a few coals containing a high proportion of resinous material it has sometimes been found necessary to adopt one or other of the alternative methods already mentioned.

The volatile products escape very readily from these mixtures and the preliminary treatment so facilitates the evolution and escape of the volatile matter that a hard, dense, smokeless fuel can be obtained practically at any temperature of carbonization from 500 deg. C. upwards. Even when made at the usual gas retorting or coke oven temperatures the coke produced can be ignited fairly readily and burns with absolute freedom in any type of grate.

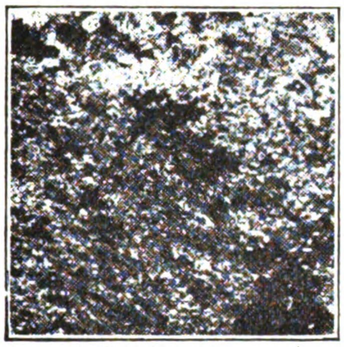
Influence of Structure.

A study of these carbonized briquettes throws a considerable light on the influence of structure on the combustibility of carbonized fuels. Research on this matter is still proceeding, and up to the present time it has not been found possible to make definite determinations of the relative combustibility of the various types of fuels that can be obtained by these processes. Sufficient has been done, however, to enable some of the principal factors involved to be determined, and these can be briefly outlined as follows:



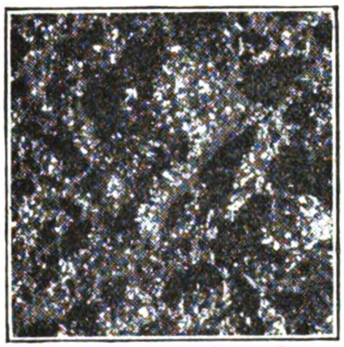
Low-temperature coke—Fuel Research Station. Natural size (Mixture of caking and non-caking coals.)

Fig. 8.



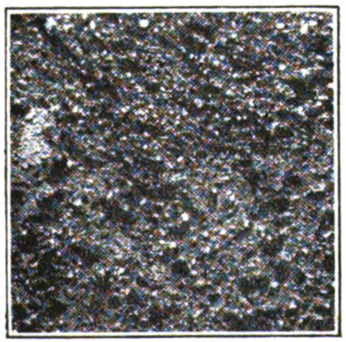
Gas coke. × 5.

Fig. 9.



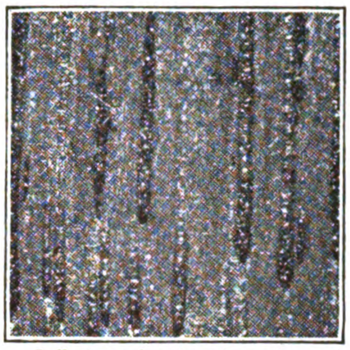
Vertical-retort gas coke. × 7.

Fig. 10.



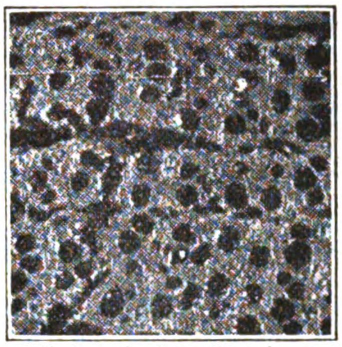
Blast-furnace coke. × 5.

Fig. 11.



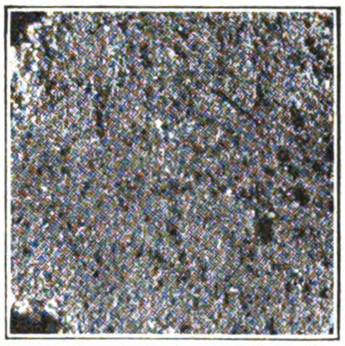
Bulk charcoal. Along the grain. × 5.

Fig. 12.



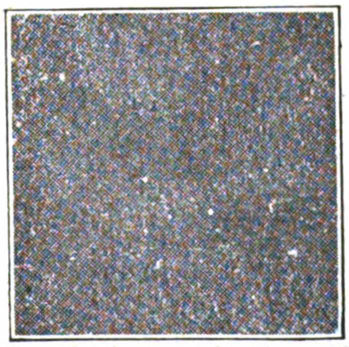
Bulk charcoal. Across the grain. × 10.

Fig. 13.



Pure coal briquette coke. Carbonised at 600° C. Coke made from mixture 40% coking and 60% non-coking coal. × 5.

Fig. 14.



Active carbon for vapour absorption. × 10.

Fig. 15.

(1) *Influence of Area of Surface*—The area of surface presented to the oxidizing gases is, of course, an important factor. Combustion can only be maintained if the area of incandescent surface exposed to the air is sufficient to maintain the temperature of a sufficient mass of the fuel above the point of ignition. The area of surface of blast furnace coke, for example, is much greater than that of a lump of anthracite, and the combustibility of the coke is therefore greater.

Generally speaking, the greater the area of surface of a fuel the greater the combustibility. Charcoal, with its highly developed cell structure, is a fuel possessing a very considerable area of surface per unit of mass, and is characterized by a high degree of combustibility.

Area of surface, again, is closely connected with degree of porosity and with the character and distribution of the pores.

(2) *Porosity*—The porosity of a carbonized fuel plays a vitally important part in connection with its combustibility, but here again it is not a question so much of the actual proportion of the pores as of their character. Very considerable differences exist between the degrees of combustibility of fuels of equal porosity, and on investigation it will be found that it is a question not so much of the total air space in a fuel as of the number of cells it contains, and of the ways in which these cells are interconnected.

In this connection it is important to consider the porosity of the cell walls. This factor is too often overlooked, and the factor of porosity is usually considered solely from the point of view of the air spaces surrounded by the walls.

In discussing the combustibility of low temperature coke, the authors have already touched upon this question. Their work leads them to the conclusion that the microscopic pores in a coke—say from the order of 1×10^{-3} cm. diameter downwards (*cf. infra*)—play an important part in determining its combustibility. It is therefore important to consider the character of the cell walls in investigating the question of porosity of coke.

(3) *Character of Cell Structure*—(a) Continuity of cell structure. The character of the cell structure of carbonized fuels was investigated by Thörner. He determined the combustibility of various blast furnace fuels, together with their porosity, and investigated the character of their cell structure by the microscopical examination of sections of the fuels. He found that the fuels which gave the best results in a blast furnace, viz., charcoal and Meiler coke, were characterized by a high degree of combustibility, and consisted, further, of cells more or less regularly arranged, which were joined to one another longitudinally. Furnace coke, on the other hand, consisted of separate unconnected cells, or groups of cells, the cells of which were composed of a dense and vitreous mass which did not allow of the passage of gas through it.

Carrick Anderson (J., 1896, 20), as a result of his investigations into the porosity of coke, confirmed this statement, and his work seemed to point to the existence of water-tight vesicles in coke. Later, Anderson and Roberts (J., 1899, 1102), in discussing the removal of nitrogen from coke by steaming, again emphasize the fact that coke "is a mass of cells, the walls of which are thoroughly vitrified and gas-tight" and therefore steaming would not be very efficacious in reducing the nitrogen in furnace coke as "except in so far as it burns away the carbon of the coke, it scarcely comes in contact with the nitrogenous constituents of the latter, protected as they are by this impervious coating."

Incidentally, Beilby in the discussion on this paper draws attention to the differences in the physical structure of splint, cannel, and coking coals, and to the difference in the carbonized products from these coals, and emphasizes the effects of the varying porosity of these fuels on the distillation products.

Taking a general view of this work, it might perhaps be too much to say that the cell structure of blast furnace coke is discontinuous; after all, the gases evolved in the later stages of distillation must get away, but there is reason to believe that the cells are connected by passages of small diameter as compared with the diameters of the cells.

Further, there is every reason to believe that the walls of these cells have been rendered vitreous and gas-tight by carbon deposition as already stated.

In the case of charcoal, on the other hand, the cells do extend longitudinally through the mass, while the authors have reason to believe that the continuity of the cell structure in fuels which have been briquetted prior to carbonization is much more pronounced than in the case of blast furnace or other coke made under normal conditions of high temperature carbonization.

This view is based upon certain properties of these fuels which are not customarily characteristic of high temperature coke, and which may be summarized as follows:

(1) The nitrogen left in the coke from these briquettes is very much lower than is the case with coke made in the usual way. The following analyses, which are typical of a large number of determinations that have been made, bring this point out very clearly:

	Raw coal	Mixture of raw coal and coke breeze	Coke from raw coal	Coke from briquettes made from mixture
Volatile matter	34.70	28.68	0.80	0.90
Ash	6.80	8.85	11.65	9.90
Sulphur	1.64	1.62	1.47	1.66
Nitrogen	1.38	1.58	1.44	1.02
Calorific value	15,500	13,500	11,950	12,350

It will be noted that although the nitrogen in the mixture of coal and coke briquetted is higher than in the raw coal, yet the nitrogen in the briquetted coke is only 1.02 per cent as compared with 1.44 per cent in the coke from raw coal. These results can be accounted for in one or two ways, depending on the method of formation of ammonia in the process of coal carbonization.

The generally accepted idea of the formation of ammonia in coal distillation is that it is a primary product formed by the decomposition of the nitrogenous matter in the coal, and that the extremely low percentage conversion is due to the decomposition of this gas in its passage through the hot coke. There is also another possibility, and that is that it is a secondary product, due to the action of nascent hydrogen on the solid nitrogenous material. Probably both reactions take place, the first at a low temperature and the second at a high temperature, particularly above 700 deg. C., where a marked increase in the quantities of hydrogen and of ammonia takes place.

Whatever the main method of ammonia formation, whether it is a primary or a secondary product, a continuity of cell structure would exert a favorable influence in the following respects: (1) In the former case, the evolution of ammonia would be accelerated, and decomposition retarded by the rapid escape of the volatile products from the heated material. (2) In the latter case, the nascent hydrogen would come into intimate contact with the nitrogenous material left in the porous solid mass, resulting in a conversion into ammonia.

As the result of a detailed series of experiments in another direction, the authors are of opinion that above 700 deg. C. the secondary formation is the predominant reaction, a conclusion which is to some extent confirmed by the above results.

(2) It has been found that coke made by the proces-

ses described above can be given marked powers of vapor absorption. Anti-gas carbon can be made by a modification of the above method which is capable of absorbing 10 per cent of its weight of heavy vapors.

A further modification can be made which has very strongly pronounced decolorizing power, and when the high sp. gr. of the fuel is taken into consideration in conjunction with the above properties (which are primarily dependent on area of surface) there seems every reason to believe that the cell structure of this material posssses a greater continuity than that of gas or furnace coke.

Effect of Size of Cells.

The dimensions of the cells play a considerable part in the combustibility of a fuel. Practically speaking, the porosity of a solid can be regarded from two aspects, viz.: (1) Cell space per unit volume, and (2) cell space per unit mass. A coke, for example, may be exceedingly voluminous, and may contain a large number of cells per unit of mass, but owing to its low apparent specific gravity may contain only a small number of cells per unit of volume. A coke of this type is obtained by customary processes of low temperature carbonization; an extreme example is shown in Fig. 1, in which a highly swollen coke is obtained with cells of large dimensions surrounded by very thin walls. The surface presented by such a fuel is very considerable, and its combustibility might be high, but on the other hand it is very fragile and will not withstand severe conditions of handling and transport, and of course would be of no use for blast furnace conditions.

The most desirable fuel would be a fuel as dense as possible, but containing a very large number of cells per unit of mass. Generally speaking, a fuel of apparent sp. gr. 1.2 with a porosity of 50 per cent would be more serviceable for general purposes than a fuel of app. sp. gr. 0.8 with the same proportion of cell space. In the former case, the cells would be exceedingly small, but the surface presented to the oxidizing gases would be so great that the combustibility would be even greater than in the former case.

The advantages of minute cells have been demonstrated in the following ways:

(1) It has been proved by an extensive series of experiments that the more finely ground the original coal mixture, the denser and the more combustible is the final product.

The influence of grinding is shown by some tests made with mixtures of caking and non-caking coals, submitted by the Fuel Research Board. These mixtures are so adjusted that the briquettes made do not expand on carbonization. In the case of the raw mixture which had been roughly crushed in a disintegrator, the briquettes made without a binder and subsequently carbonized presented the appearance of being covered with a mass of fairly large bubbles, giving a more or less irregular appearance to the briquette. As the mixture, however, became more and more finely ground these bubbles became smaller and less numerous and the surface became smoother and more uniform in apearance. At the same time the app. sp. gr. of the carbonized fuel uniformly increased. The sizing tests of the above mixtures are given below, together with the apparent specific gravity (no sizing test was made of the raw material).

It is evident that fineness increased the uniformity and density of the resulting product, due to the diminishing size of the cells, and extensive experiments over many years have proved to the authors that at the same time the combustibility of the fuel increases.

Table II.

	No. 2.	No. 3.	No. 4.	No. 5.
	Pct.	Pct.	Pct.	Pct.
Remaining on 20-mesh...	5.82	1.74	1.76	2.38
Remaining on 30-mesh...	11.37	1.62	0.68	0.32
Remaining on 60-mesh...	25.88	19.22	10.13	3.02
Remaining on 90-mesh...	22.03	32.15	35.22	27.67
Remaining on 120-mesh...	7.32	7.43	7.84	10.17
Remaining on 180-mesh...	2.22	2.51	2.84	4.14
Through 180-mesh...	25.36	35.33	41.53	52.30
Apparent sp. gr.........	0.933	1.031	1.034	1.103

(2) To produce activated carbon it is necessary to grind down to a size comparable with that required for dust firing. The cells in the resulting fuel become extremely minute, as is shown by Fig. 15. This fuel is easily the most combustible product produced by the authors' processes. Incidentally it has recently been shown by Harkins and Ewing (J. Amer. Chem. Soc., 1921, 43, 1787—1802) that pores of a greater diameter than 1.2 × 10^{-3} cm. have no absorptive action on vapors. The high absorptive powers of this carbon can only be satisfactorily accounted for by the assumption that it contains a large proportion of very minute pores.

(3) The surface offered by a material of this type permeated by minute cells, is enormous, and would be very much greater than that of a coke with a comparatively small number of cells enclosed by thick walls.

When heated in an oxidizing atmosphere the points of contact presented to the action of the oxygen would be very much more numerous than in the case of furnace coke, and, as has already been shown, this material continues to burn under conditions where the radiation and cooling losses are so considerable that ordinary furnace or gas coke would be extinguished in a few seconds.

Combustibility of Carbonized Fuels—Summary.

To summarize the above results:

By careful attention to the structure of a fuel it is possible to produce at high or low temperatures of carbonization a fuel of high degree of combustibility, high degree of hardness, and high apparent sp. gr.

The structure of this fuel has the following characteristics: High degree of porosity. Considerable area of surface per unit of mass. Pronounced cell structure. Pronounced continuity in cells. Large proportion of minute cells. Pronounced porosity of cell walls.

The Blast Furnace.

The third largest consumer of fuel in England is the blast furnace. In normal times the coke consumption in this country for the manufacture of pig iron amounts to about 12,500,000 tons per annum. The average consumption of coke per ton of iron is for the whole country about 25 cwt., and it is a remarkable fact that this figure is no lower, and is probably a little higher than it was 40 years ago.

When we consider the enormous progress that has taken place in other branches of industry during this period, and especially when we realize the amount of detailed scientific work that has been performed in connection with blast furnace practice, and the high degree of scientific control that has been introduced, it seems at first sight difficult to understand why this industry alone should have marked time for so long a period. A very slight acquaintance with the idiosyncracies of the blast furnace, however, is sufficient to bring home to the most ardent economist some of the difficulties involved in a saving of fuel. Koppers in his paper stated that "the blast furnace is still a mystery, and even today the blast furnace manager does not manage the blast furnace, but the blast furnace manages the manager." All that that unfortunate being wants is to be left in peace, and not be bothered with anything that will add to the complexities he has to face; and his attitude can be readily understood. He looks after his plant with just the same care as a chemist looks after a delicate quantitative analysis. Every ounce of material entering and leaving the furnace is carefully weighed and analyzed; every unit of heat that enters or leaves is accounted for, and from the data supplied by his chemical staff the blast furnace manager can draw up a chemical and thermal balance sheet of a character which is extremely difficult to criticize.

Further, the blast furnace manager has behind him the monumental work of Sir Lowthian Bell, whose classical researches on the chemical phenomena of iron smelting have dominated blast furnace practice for the past 50 years. Bell's work drove home with absolute and complete conclusiveness that in a blast furnace operating with coke as a fuel the indirect reduction of the Cleveland ore ceases when the relative proportions of CO and CO_2 are as 2:1.

Chemically, it is possible completely to convert CO and CO_2 by iron oxide, but at temperatures below 480 deg. C., this operation proceeds with such extreme slowness that in a blast furnace "the action would be delayed until the mineral reached a level in the blast furnace where the heat would resolve any CO_2 into CO" (J., 1890, 709).

This ratio $CO:CO_2 = 2:1$ at once fixes the thermal efficiency of furnaces working Cleveland ore at a minimum of 60 per cent reckoned on the available energy of the coke charged into it, and led Bell to state that it was "useless to hope to smelt a ton of gray iron from Cleveland stone yielding 41 per cent of pig iron metal with anything notably under 20½ cwt. of coke."

Assuming the ratio $CO:CO_2 = 2:1$, the chemical reactions in a blast furnace can be represented by the equation:

$$Fe_2O_3 + 9CO = 2Fe + 6CO + 3CO_2$$

which corresponds to a carbon consumption of 19.3 cwt. per 20 cwt. of pig iron produced, a figure which, after allowing for the impurities customarily present in furnace coke, agrees with Bell's figure of 20½ cwt. of coke. This figure meets with both the chemical and thermal requirements of the reaction.

This dictum, supported by researches of unquestionable accuracy and backed by nearly 50 years of accumulated experience, at once faces those who venture to suggest that a modern blast furnace is not an industrial machine of unquestioned perfection and that there is room for effecting economies in its operation. And yet, despite Bell's researches, despite the lessons of British experience, despite the failures that have attended the efforts of British fuel reformers in the past, the authors are still venturesome enough to suggest that the limit of fuel economy in British blast furnace practice has not been reached, but that substantial economies are still possible, and that even Cleveland ore will ultimately be smelted with as low a consumption as 12 cwt. of coke per ton of pig iron produced.

Fuel Consumption in Blast Furnace Practice.

Before proceeding to give reasons for this assertion it might be of interest to note some figures of fuel consumption in blast furnace practice that are available.

(1) *British Practice*—Clements (J. Iron and Steel Inst., 1920, I., 125) gives a valuable summary of results obtained in 17 British blast furnaces. These results can be summarized as in Table V.

N. B.—The low carbon consumption as compared with coke is due to the fact that both moisture and ash are included in the weight of coke charged into the blast furnace.

The differences in results obtained in different districts are to some extent accounted for by differences in the ore, but it will be noted that several instances exist which show a carbon consumption below Bell's theoretical minimum.

Table V.

District	Coke consumption per ton of pig iron in cwt.			Carbon consumption per ton of pig iron in cwt.			Furnaces
	Max.	Min.	Avg.	Max.	Min.	Avg.	
Middlesbrough ..	23.0	21.08	22.3	19.78	18.13	18.77	3
Midland	31.5	25.05	29	24.88	19.76	23.37	11
S. Wales	22	18	20	16.8	15.77	16.19	3

Turner ("Metallurgy of Iron and Steel," 3rd Edn., p. 205) quotes statements of S. Staffordshire managers that by working with soft coke in admixture with hard coke the fuel consumption was sometimes reduced to 16—17 cwt. in furnaces of only moderate size.

(2) *American Practice*—Howland (J. Amer. Inst. Min. Eng., Mar., 1916) gives detailed particulars of 26 American furnaces, all working with the same kind of ore, which showed very considerable differences in the coke consumption per ton of pig iron produced, the maximum being as high as 24 cwt. of coke per ton and the lowest 15 cwt. per ton, the carbon consumption being 20 and 12.6 cwt. respectively.

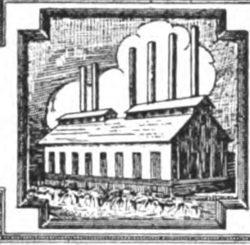
It is, therefore, not entirely a question of the ore used.

(3) *Charcoal Furnaces*—Lastly, charcoal furnaces, which are generally of much smaller dimensions than coke furnaces, show figures of carbon consumption which are startlingly low as compared with coke furnaces. Bell in fact quotes one case in which the carbon consumption was as low as 10.58 cwt. per ton of iron produced.

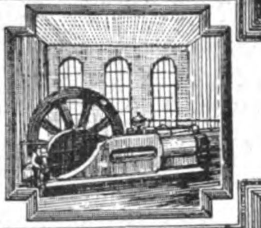
Combustibility of Coke as a Factor in Reducing Fuel Consumption.

The gap between some of these figures and the 19.35 cwt. which represents the minimum required to satisfy Bell's ideal is so considerable that the question arises whether some factor exists which was not taken into account in Bell's calculations. Howland definitely states that the only method of accounting for this considerable difference obtained in furnaces working the same ore is by assuming that the combustibility of the coke was far greater in the more efficient furnaces than in the less efficient ones. This opinion is confirmed by the results obtained in charcoal furnaces. Charcoal as a fuel is far more combustible than any type of coke, and it is significant that the fuel consumption in charcoal furnaces is lower than anything which has ever been obtained in coke furnaces. The interesting South Staffordshire results quoted also tend in the same direction.

Koppers considered this factor so important that he went so far as to advocate the use of coke carbonized at a temperature below 800 deg. C., so as to secure a more combustible fuel. (The authors, while they agree with Koppers as to the necessity for a combustible coke, do not consider the method suggested of carbonizing below 800 deg. C. to be a satisfactory solution.)



STEAM POWER DEPARTMENT



Calculating Heat Losses in Furnaces

A New Method For the Determination of the Heat Losses Due To Incomplete Combustion.

*By O. I. HANSEN, M. E., Copenhagen, Denmark

OUR investigations on furnaces in boilers has made it evident that in far more cases than it is generally expected unburned gases are present in the flue. This seems to be the case both in ordinary steam producing boilers as well as in boilers for domestic heating purposes and even in cases where the contents of carbonic acid does not exceed 8-9 per cent.

In ordinary furnace installations the unburned gases are composed of carbonic oxide alone or carbonic oxide mixed with hydrogen or methyl hydride or both. While the percentage of carbonic oxide may vary considerably the amounts of hydrogen and methyl hydride always are limited to quite small quantities, which are rather difficult to examine directly.

Drawing gas out of coal as it is done in ordinary gas retorts we get approximately 5 cubic feet gas per one lb. of coal. As part of this 2.5 cu. ft. is hydrogen and 1.6 cu. ft. methyl hydride. Of course the processes occurring in a furnace is not the same as in a gas retort but generally speaking, we are able to treat both processes in the same way.

Provided we use coal of 12,600 Btu per one lb. coal, heating value, a perfect combustion will require 168 cubic feet of atmospheric air (carbonic acid 14 per cent) we conclude that the flue gas as a maximum contains:

$$\frac{2.5}{168} \times 100 = 1.48 \text{ or appr. } 1.5 \text{ per cent } H_2$$

$$\frac{1.6}{168} \times 100 = 0.96 \text{ or appr. } 1.0 \text{ per cent } CH_4$$

For just short periods the amounts may be larger, but as a fair approximation for this estimate the maximum quantities are 1.5 per cent H_2 and 1.0 per cent CH_4.

We exclude from our investigations quantities of heavy carburetted hydrogens (C_nH_m) which very seldom are present in the flue gas in a larger percentage than 0.1 per cent, and we are quite unable to measure such small quantities, except in laboratories.

It is under ordinary circumstances very difficult to apply the results attained through the analysis by means of an ordinary Orsats Apparatus for the determination of the heat losses due to incomplete combustion. The apparatus is very practicable as long as it is only used in order to determine the percentage of carbonic acid, but several difficulties arise when it comes to the determination of oxygen and carbonic oxide.

The absorption of oxygen in pyrolallic acid is generally so slow and intricate that it is unpracticable for ordinary purposes. Furthermore the amount of this acid contained in the ordinary Orsat pipette is so small and will only allow for about 50 analyses, and if kept in the bottle the acid becomes impoverished within only a few days.

The process would be quicker by testing with phosphorus than by testing with pyrogallic acid, but the determination of oxygen proves to be impracticable whenever the flue gas contains only small quantities of heavy carburetted hydrogens as the phosphorus then is not so certain to absorb all oxygen.

The determination of carbonic oxide is generally done by means of hydrochloric or ammoniacal solution of cuprous chloride. This way of determining the amount of carbonic oxide is even more slow and uncertain than the determination of oxygen because cuprous chloride absorbs the amount of oxygen, which eventually has not been absorbed by the pyrogallic acid, further does the solution of cuprous chloride absorb very slowly and there is finally the possibility for this solution to give up part of the carbonic oxide already absorbed.

Besides carbonic oxide the flue gas may contain hydrogen or methyl hydride as already mentioned, a fact, which has not always been the subject of investigators' attention.

It is of very great importance to have the sample of flue gas at an invariable temperature throughout the trial, because a deviation in temperature of only 3 deg. Centigrade will cause an error in the determination of the volume amounting to one per cent and the amount of unburnt gases in the flue gas is in many cases even less than one per cent.

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*Translated and transcribed into American Units for heat and spare by F. V. Hangsted, M. E.

In order to avoid errors to this effect the following should be observed. The apparatus for analyzing the flue gases should be brought to the spot where the trial is to take place about an hour before the work starts in order to make the temperature of the spot and the temperature of the apparatus balance. After being taken into the apparatus the sample must be given sufficient time to adopt the temperature of the latter. Having observed this the actual time for making each separate analysis must be as short as possible in order not to allow for any greater deviation in temperature during that period.

In order to get a quick result in determining all losses of heat due to unburned gases without using the troublesome and slow absorption method, we applied a capillary tube made out of platinum and burned our sample of flue gas in this after having withdrawn its contents of carbonic acid.

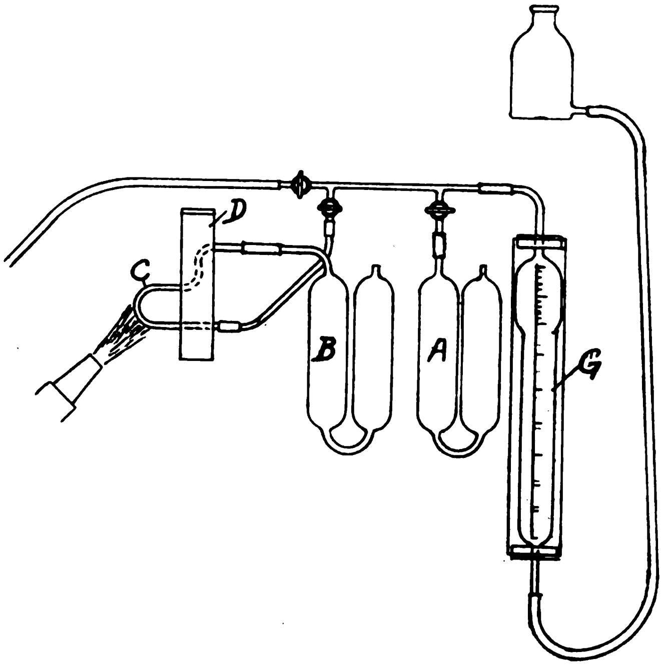


Fig. 1.

After a long line of experiments we concluded in the apparatus as shown below:

Our apparatus is an ordinary Orsat apparatus with two absorption pipettes, one (A) containing solution of caustic potash and the other (B) water. The platinum capillary tube (C) is kept cool on part of its length through the vessel (D) containing water. A gasoline heating lamp is applied for the heating of (C).

The application of this apparatus is as follows:

After having drawn a sample of flue gas of 100 cubic centimeter volume into the graduated measuring tube (G) we examine the contents of carbonic acid through absorption in (A). After having done this the gas is driven slowly through the capillary tube (C), which is heated, and passes over into (B), where it is cooled. When all of our sample is contained in (B) the heating lamp is removed from (C), which cools off quickly. The gas is then driven back into the graduated measuring tube (G) and we are able to measure any resultant contraction. In order to be quite certain about the result it is recommended that this operation be repeated for each sample. Then make a determination of the amount of carbonic acid, which has been produced through the combustion in the capillary tube, and our analysis is finished. It is proved to be possible to make this analysis in 5 or 6 minutes.

It is of importance to heat the capillary tube to a sufficiently high temperature. The use of an ordinary spirit lamp has been tried for this purpose, but though carbonic oxide and hydrogen burned, methyl hydride in many instances did not burn until we applied a gasoline heating lamp.

In some of our experiments we used a 50 per cent mixture of glycerine and water in the pipette (B) in order to avoid any absorption of carbonic acid in this pipette, but as it proved to be impossible to prevent small quantities of this mixture to slip over into the platinum capillary tube and develop a large amount of carburetted hydrogen during the combustion, we realized that this mixture was unserviceable.

For the following calculations we presume the flue gasses composed as designated by the following percentages by volume:

CO_2 per cent oxygen
O_2 per cent carbonic acid
CO per cent carbonic oxide
H_2 per cent hydrogen
CH_4 per cent methyl hydride

besides nitrogen and water vapor, which is immaterial in this estimate.

We further presume that after our first absorption the percentage (cubic centimeters) of carbonic acid measures CO_2, after the combustion in the capillary tube the contraction is c, and the last determination of carbonic acid shows a percentage by volume of co_2.

At the combustion in the capillary tube the following reactions took place:

For CO burned to CO_2

$CO + \frac{1}{2} O_2 = CO_2$, one cubic centimeter of CO requires ½ cubic centimeter O_2 and produces one cubic centimeter CO_2, the resultant contraction is ½ cubic centimeter.

For H_2 combining with O_2 the reaction is

$H_2 + \frac{1}{2} O_2 = H_2O$, one cubic centimeter H_2 combines with ½ cubic centimeter O_2 and produces one cubic centimeter H_2O, the resultant contraction is 3/2 cubic centimeters.

For CH_4 burned to CO_2 and water the reaction is $CH_4 + 2\ O_2 = CO_2 + 2H_2O$, one cubic centimeter CH_4 requires two cubic centimeters O_2 and produces one cubic centimeter CO_2 and 2 cubic centimeters H_2O, the resultant contraction is two cubic centimeters.

The total contraction is hence:

(1) $c = \frac{1}{2} CO + 3/2\ H_2 + 2CH_4$, and the last determination of carbonic acid shows

(2) $co_2 = CO + CH_4$.

c and co_2 are determined by the analysis, but for the determination of CO, H_2 and CH_4 we have only two equations.

The determination of the percentages of each separate gas would require an examination of the amount of oxygen consumed at the combustion in the capillary tube. As we do not know the percentage amount of oxygen present in the flue gases, this examination would require the removal of all oxygen and the aspiration of a certain volume of atmospheric air before we let the sample pass through the capillary tube, where the combustion takes place, after this we would have to remove all oxygen once more and would then be able to determine the amount of oxygen consumed in the combustion.

This method however is too intricate for ordinary purposes and the gain in exactness of our final result is minimal, partly due to the fact that before drawing in atmospheric air we would have to discharge about 50 per cent of our sample, which means that the inaccuracy in our observations would be doubled. We therefore worked out a method for the determination of the heat losses based on the contraction (c) and the amount of carbonic acid produced during the combustion (co_2).

The available heating values per one cu. ft. of CO, H_2 and CH_4 are as follows:

CO,	342.3 Btu
H_2,	289.8 Btu
CH_4,	954.2 Btu

Contemplating these figures and the two equations (1) and (2) we see that in having determined certain values of c and co $_2$ the heat losses will reach a maximum if the flue gas contains only carbonic oxide and methyl hydride and no hydrogen and the heat losses will reach a minimum in case the flue gases contains hydrogen and carbonic oxide and no methyl hydride.

Taking each of these two cases separately we find:

When $H_2 = O$ (heat losses at a maximum)

$$c = \tfrac{1}{2}\,CO + 2CH_4$$
$$co_2 = CO + CH_4$$

Or we may write

$$\left.\begin{array}{l} CH_4 = 1/3\ (2c - co_2) \\ CO = 2/3\ (2co_2 - c) \end{array}\right\}(\propto)$$

When $CH_4 = O$ (heat losses at a minimum)

$$c = \tfrac{1}{2}\,CO - 3/2\,H_2$$
$$co_2 = CO$$

Or we may write

$$\left.\begin{array}{l} H_2 = 1/3\ (2c - co_2) \\ CO = co_2 \end{array}\right\}(\beta)$$

In the following we use the symbol w to designate the actual heat losses, the symbol $w\propto$ to designate the maximum and $w\beta$ the minimum heat losses, we then find:

$$w\propto = 3.42\ CO - 9.54\ CH_4$$

Inserting the values of CO and CH_4 from ($\propto$)

(3) $w\propto = 4.08\ c - 1.38\ co_2$

In the same way the minimum

(4) $W\beta = 1.93\ c + 2.45\ co_2$

We then find w as the intermediate between $W\propto$ and $w\beta$

(5) $w = \tfrac{1}{2}\,(w\propto + W\beta) = 1.91\ co_2 + 3.01\ c$

In doing so the error at a maximum would be

(6) $dw_{max} = \tfrac{1}{2}\,(w\propto - w\beta) = 0.535\ (2c - co_2)$

The heat losses calculated per one lb. of fuel is

(7) $W = Fw = (3.01\ c + 1.91\ co_2)$

Where F is the cubic ft. volume of flue gas produced per one lb. of fuel.

$$F = \frac{C - C'}{CO_2 - co_2} \times \frac{359.5}{12} = \frac{C - C'}{CO_2 - co_2} \times 29.93$$

Where

C is percentage by weight of carbon in the fuel

C' is percentage by weight of carbon in the ashes

co_2 and CO_2 are percentage by volume of carbonic acid by O° Centigrade and atmospheric pressure (29.922").

Formular 7 will give the exact heat losses in case the flue gas contains only CO or CO mixed with equal quantities of H_2 and CH_4. Our tests however have shown that in using gassy fuel we generally find both hydrogen and methyl hydride together with carbonic oxide, in such cases where we were able to measure any amount of unburnt gases at all. This indicates that under ordinary conditions the error will generally be much smaller, than the above estimated maximum error.

Using coke one would be apt to think that we should only find CO_2 and CO in the flue gas. Our tests however have shown the presence of measurable quantities of f. inst. H_2 in furnaces using coke. This is probably due to the fact that the moisture does not evaporate all at once but part of it is decomposed into H_2 and O, or the presence of H_2 may be due to a certain percentage of vapor in the atmospheric air.

The heat losses due to unburnt gases in furnaces using coke might be estimated by means of the same formular (4).

The heat losses per 1 lb. of fuel is hence

(8) $W = Fw = F\ (1.93\ c + 2.45\ co_2)$.

The validity of formular 7 will be appreciated if we compare its inaccuracy with the error in observation on the Orsat apparatus. An experienced man will be able to read the volume with an error not larger than 0.1 cubic centimeter, and if we further take into account a small deviation in temperature we may estimate this error to be 0.2 cubic centimeter.

Differentiating 7 we find

$$dW = F\ dw = F\ (3.01\ dc + 1.91\ dco_2)$$

In this equation dco_2 will not have its maximum value at the same time as dc has it, therefore the following three cases should be investigated.

$$dc = -0.2;\ dco_2 = \left\{\begin{array}{l} 0 \\ -0.2 \\ -0.4 \end{array}\right.$$
$$dc = -0.2;\ dco_2 = \left\{\begin{array}{l} -0.2 \\ 0 \\ -0.2 \end{array}\right.$$
$$dc = 0;\ dco_2 = -0.4$$

The cases:

$$dc = \pm 0.2;\ dco_2 = 0$$

will show the biggest errors, we find:

(9) $dW_{max} = 3.01 \times 0.2\ F = 0.602\ F$, Btu per 1 lb. of fuel.

Calculating this error as percentage of the heating value of the fuel, we find

$$dW_{max}\frac{100}{B} = 0.602\frac{F}{B}\ 100 \text{ per cent.}$$

From (6) we find

$$dW_{max} = F\ w = 0.535\ (2c - co_2)\ F,$$

and as percentage of the heating value

$$dW_{max}\frac{100}{B} = 0.535\ (2c\frac{F}{B}\ co_2) - 100, \text{ per cent.}$$

According to these results we are now able to estimate the proper limits for the errors in each separate case.

We now want to show an example, presuming that the flue gas is actually composed of

CO_2,	14 per cent by volume
CO,	2 per cent by volume
H_2,	0.4 per cent by volume
CH_4,	0.6 per cent by volume

Calculating the actual values of c and co_2

$$c = \tfrac{1}{2} \times 2 + 3/2 \times 0.4 + 2 \times 0.6 = 2.8$$
$$co_2 = 2 + 0.6 = 2.6$$

Then the actual loss in heat will be

$$2 \times 3.423 + 0.4 \times 2.898 + 0.6 \times 9.542 = 13.73 \text{ Btu.}$$

Calculating the heat losses according to 5

$$w = 1.91 \times 2.6 + 3.01 \times 2.8 = 13.39 \text{ Btu.}$$

The actual error in using 5 is then

$$13.73 - 13.39 = 0.34 \text{ Btu.}$$

Calculating the maximum error according to 6 we find

$$dw_{max} = 0.535\,(2 \times 2.8 - 2.6) = 1.61 \text{ Btu.}$$

The maximum error in observation is as shown above 0.60 Btu per one cubic ft. of flue gas or in this case just twice as big as the actual error in calculation.

We will now estimate the error as a percentage by the heating value of the fuel.

Using coal with a heating value 12,600 Btu and 192 cu. ft. of flue gas per one lb. of coal, then the actual heat losses will be:

Using the figures from the example above

$$13.73\,\frac{192}{12{,}600}\,100 = 21 \text{ per cent of the heating value}$$

of the coal.

Inserting the result attained by 5 in the same way

$$13.39\,\frac{192}{12{,}600}\,100 = 20.5 \text{ per cent of the heating}$$

value of the coal.

The maximum error in calculation is

$$1.61\,\frac{192}{12{,}600}\,100 = 2.46 \text{ per cent.}$$

But the actual error in calculation is only

$$0.34\,\frac{192}{12{,}600}\,100 = 0.50 \text{ per cent.}$$

And the maximum error in observation is

$$0.60\,\frac{192}{12{,}600}\,100 = 0.92 \text{ per cent.}$$

The error in calculation will only reach the above estimated maximum value in case the flue gases besides carbonic oxide contain either methyl hydride alone or hydrogen alone. But our investigations have proved as already mentioned, the assumption that carbonic oxide is present either alone or together with both methyl hydride and hydrogen in flue gases from gassy fuel. This indicates that in most cases the actual error in calculating according to the above given method is less than 0.5 per cent of the available heating value of the applied fuel and generally even smaller than the probable error in observation.

In case the flue gases have a high percentage of carbonic acid along with a measurable amount of unburnt gases it is quite probable that the oxygen present in our sample will not be large enough to accomplish a perfect combustion in the capillary tube. We would then have to take a certain amount of atmospheric air into the apparatus, which again may require the discharge of a certain part of the sample in order to make room for the air.

For instance if the fuel is composed as follows:

Percentage by weight of carbon	76
Percentage by weight of oxygen	8
Percentage by weight of hydrogen	5

And the flue gas is composed as follows:

Percentage by volume of CO_2,	15
Percentage by volume of CO,	3
Percentage by volume of CH_4,	0.5
Percentage by volume of H_2,	0.5

Then the amount of O_2 will be:

$$O_2 = 20.9 - CO_2 \times 1.125 - CO \times 0.73 + CH_4 \times 0.457 + H_2 \times 0.187,$$

inserting the values of CO_2, CO a. s. f.

$$O = 20.9 - 15 \times 1.125 - 3 \times 0.73 + 0.5 \times 0.457 + 0.5 \times 0.187$$
$$O_2 = 2.13 \text{ cubic centimeter.}$$

Contemplating the reactions during the combustion in the capillary tube as already mentioned, we are able to calculate the amount of oxygen necessary for each reaction, we find:

3 cubic centimeter of CO
requires $0.5 \times 3.0 = 1.5$ cu. centimeter O_2
0.5 cubic centimeter of CH_4
requires $2.0 \times 0.5 = 1.0$ cu. centimeter O_2
0.5 cubic centimeter of H_2
requires $0.5 \times 0.5 = 0.25$ cu. centimeter O_2

After having absorbed the percentage of CO_2 (15 per cent) we are able to take into the apparatus

$$15\,\frac{20.0}{100} = 3.13 \text{ cubic centimeter oxygen}$$

for the combustion then is available

$3.13 + 2.13 = 5.26$ cubic centimeter oxygen, which is ample in this case, as only 2.75 cubic centimeter is required.

In order to give a final conclusion of what our investigations as described in this article have accomplished, we may say: It is possible to make a calculation of the heat losses due to the presence of unburnt gases in the flue, which is exact enough for ordinary purposes. This calculation leads to a determination of the heat losses, which gives a far more exact result than the methods formerly used. These methods did not generally indicate but the percentage of carbonic oxide and the exactness was even very doubtful.

As long as our investigations are only made in order to determine the quality of the combustion in the furnace and not for the purpose of examining the evaporation, our device is very practicable, because within a few minutes it determines whether or not any unburnt gases are present in the flue gas, and the apparatus is always ready for use, this is a great advantage compared with the ordinary Orsats apparatus containing pyrogallic acid and cuprous chloride as these solutions must be renewed quite frequently.

Among those numerous cases in which our method has proved to be very advantageous its application on continuous running furnaces in boilers for domestic heating has been especially successful. Once running, it is very difficult in some cases even impossible to determine directly the amount of heat used efficiently in these furnaces. The determination of the efficiency in such cases can be made indirectly through a deduction of all heat losses from the amount of heat actually produced by a perfect combustion of the fuel. It is therefore of great importance to be able to determine all heat losses with the largest possible exactness, and as to the heat losses due to incomplete combustion this can be accomplished through the method described in this article.

Pulverized Coal in the Steel Plant

Application of Pulverized Fuel to Open Hearths, Soaking Pits, Heating Furnaces, Sheet and Pair Furnaces and Some of the Results Obtained.

By W. H. SEARIGHT

POWDERED coal has made such rapid strides in the last few years that it must be taken into account not only for the generation of steam in power plants, but also for its varied uses in the steel industry.

This form of fuel has been tried in the following types of steel mill furnaces: open hearth, soaking pits, heating furnaces, sheet and pair furnaces, annealing furnaces, and several other types found in some mills.

From the foregoing list it can be readily seen that a thorough study of the combustion of coal should be made, as greater economies can be effected when the laws that govern this method of firing are known. The burning of coal is similar to that of oil or gas, and the greater the degree of pulverization (and this is especially true of low ash coals) the more nearly the combustion approximates liquid and gaseous fuels.

Two important characteristics of the fuel to be burned must be taken into account, the volatile content of the coal and the ash content. In the proper designing of combustion chambers, these items receive first consideration.

It is not necessary for coals to be high in volatiles and low in ash. Anthracite culm, which is naturally low in volatiles and extremely high in ash, can be readily burned. Even Rhode Island anthracite, when pulverized and used for the generation of steam, exceeds all expectations.

Open Hearth Furnaces.

The progress made by powdered coal in its application to the open hearth furnace has been slow when compared to its progress in other directions. The principal reason for this condition can be traced directly to the lack of interest shown by the majority of furnace operators who are ignorant of the proper methods of firing when powdered coal is used. Nearly every failure in open hearth furnaces has been due to extreme temperatures burning out the roof, side walls and end walls. Therefore it remains for the fuel to be properly controlled as gas and oil are. Besides this, another serious objection to the use of powdered coal in this type of furnace confronts us.

In order that the large amount of dust which is carried into the slag chamber be removed, the furnace must be built in such a way as to accomplish this removal quickly and easily. It is also well to provide for extra large flue areas in the checker work. The operator does not like to see his furnace undergo such radical changes as he invariably expects to have trouble getting out his heats with powdered coal. This pessimistic attitude is due largely to his unfamiliarity with this form of fuel.

However, some open hearth furnaces have been fired with powdered coal successfully. In one of these cases the average fuel consumption based on several months' run was approximately 500 pounds per ton with all metal charged cold. Another record run over a period of one month was a production of 3,300 tons of ingots with a fuel consumption averaging 441 pounds per ton of metal and a maximum fuel consumption of 700 pounds per ton. The melting loss of the above run was from 8 per cent to 10 per cent.

Powdered coal shows a distinct advantage over producer gas fired furnaces as to fuel consumption, a good average for a producer fired furnace being the equivalent of 600 pounds of coal.

Soaking Pits.

Powdered coal has been used in the operation of soaking pit furnaces. These pits are of the non-regenerative type having a capacity of 260 tons per day charging 300-pound ingots. When the ingots are charged cold, which is usually the case, the fuel consumption approximates that of a reheating furnace of the non-continuous type.

Heating Furnaces.

Because of the problem of ash disposition on entirely satisfactory type of continuous heating furnace has been designed. Furnaces of the continuous billet type now using powdered coal have been built for some other method of firing. Nearly all have short combustion chambers which allow only a small percentage of ash to be precipitated in molten form, the balance being carried along in the flue gases. As the velocity of the gases decreases the majority of the ash is deposited throughout the length of the furnace and the flues in the form of dust.

In furnaces used for heating short billets the accumulation of dust and slag is objectionable. The labor which this entails would frequently offset some of the advantages of coal in the powdered form. However, when slabs occupy the entire width of the furnace the accumulation does not become so troublesome.

Varying results in fuel consumption have been obtained from different types of continuous furnaces. The range is from 90 pounds to 190 pounds of coal per ton of billets. The low figure was obtained by charging billets at 1,000 deg. F., but an average fuel consumption of 150 pounds per ton was made with a good grade of coal in a furnace designed for gas firing.

There are a large number of heating furnaces of the "in and out" type in operation, using pulverized coal as fuel. Although the dust from the ash has been troublesome at times, operators are most enthusiastic over the results obtained as compared with hand firing. In furnaces of this type one of the great economies effected by the use of powdered coal is the reduction of oxidation losses. When steel prices were at the peak, the saving at a plant operating a heating furnace for rerolling scrap was several thousand dollars in oxidation losses alone. The cost of pulverizing coal at this plant was abnormally high because of the small output used. Nevertheless the statement was made that no other method of firing would be considered, even though the cost of pulverizing was doubled. The savings in fuel after deducting the cost of pulverizing (all items including overhead taken into account) gave a good return on the investment; and when the savings from reduction of oxidation losses were added, the result was exceptional. A waste heat boiler was used in conjunction with this furnace. In general terms, a reduction of approximately 75 per cent is made in oxidation losses with powdered coal firing.

Sheet and Pair Furnaces.

The sheet mill industry has recognized the many operating advantages of powdered coal. It was first adapted to furnaces designed for hand firing and the results were very unsatisfactory. Even with coal of low ash content, a large amount of dust was carried into the heating chamber, settled on the sheets and was rolled into their surface, spoiling them and ruining the rolls. In some cases it was necessary to sweep the ash from the sheets upon their removal from the furnace. Even this method, however, did not take care of the ash that settled between the sheets when they stood against the wall.

The adoption of a large combustion chamber not only made possible the proper combustion of fuel, but made allowance for the expansion of the gases and the precipitation of the ash before it reached the working chamber, thus reducing the number of sheets spoiled by settling of the ash.

The use of the individual powdered coal bin, with its own coal feeders, burners and blower for each unit of one sheet and one pair furnace, gaves a greater flexibility of control and reduces the chances of shutdown as far as fuel is concerned.

The fuel consumed in sheet and pair furnaces will run from 26 pounds to 325 pounds per ton of sheets produced. Furnaces making high grade sheets over a period of several months average about 300 pounds of coal per ton of sheets.

Annealing Furnaces.

Powdered coal has been applied only to sheet and tin plate annealing furnaces of the "in and out" type. In its early application the design of the furnace then in use decided the location of the burner, as well as the size of the combustion chamber. When new sheet mills were built with the intention of utilizing powdered coal, the proper design and construction of combustion chambers was possible. Each chamber is served, generally, by separate equipment, thus enabling a more accurate control of flame and temperature. The size of the furnace, the amount charged and the quality of the sheets produced are some of the determining factors of fuel consumption, which varies from 150 pounds to 400 pounds per ton of sheets.

Conclusion.

The foregoing facts give a brief outline of the results that can be expected by the adoption of powdered coal. The advantage derived from this type of fuel is largely a reduction in coal consumption, although all other factors must be given fair considered.

DISINTEGRATION OF BLAST FURNACE LININGS

By L. O. Brightbill

Disintegration of blast furnace linings has been a problem of much worry to many furnace superintendents.

Some time while using the same material, one blast will be of long duration and then again very short.

This is blamed sometimes on the mason work; other times on the quality of brick. But personally I believe that most of this is due to the blowing in.

I have in mind a furnace that was started off at a rapid gate. Within a few weeks the walls were practically useless. Again the blast ate out the lining, so now I consider a happy medium between the two to be the best.

One furnace under my charge ran sixteen years with the same lining. This furnace used a very high zinc ore. Being a small furnace and working cool stock line the "oxide zinc" formed a coating on the walls, which was a protection to the walls. After this same furnace had been enlarged, the zinc worked exactly opposite, helping to cause a disintegration of the lining, lodging in downcomers and flues.

Some times the furnaces will scaffold on one side, causing the blast to go up the opposite side, making it wear out in a very short time.

I have noted particularly when the stock is good and dry that is used in blowing in a furnace, I have invariably had good success with the entire blast. But when the ore is wet, causing it to cake on the wall, in blowing in I have had more or less trouble with that blast, the lining lasting only a short while.

UNIVERSITY OFFERS COURSE IN METAL MARKETING

To acquaint students with the fundamental facts underlying the minerals and raw materials situation the school of commerce, accounts and finance of New York university, New York, has scheduled a course for the coming school year which will deal with this subject. The character and source of supply, the methods and cost of preparing materials for market and their relation to other lines of business are general topics to be given consideration. Dr. Ernest Lilley, geologist and mining engineer, is to be the lecturer.

Some of the discussions which will be of interest to the iron and steel industry will be the character of coal reserves and resources, problems of the American coal, coke and coal tar industries and the water and super power systems. During the spring term which will be devoted to the commercial geology of the metals the class will consider, under the iron group, the mining and preparation of iron and steel, world problems in iron ore conservation and utilization, the major and minor alloy bases. Flux materials, refractories and insulators and abrasives will occupy the attention of the process materials section. One of the last groups will take up the nonferrous metals from the standpoint of the American copper industry, problems of the lead and zinc industries, major imported metals as tin and nickel and the minor metals.

The course is divided into two sections, one being a fall and the other a spring term. Classes are to be held at the Washington square division of the university.

NEWS OF THE PLANTS

The Maryland Steel Rolling Company, Baltimore, Md., has acquired the plant and business of the Trenton Steel & Wire Company, Mackenzie Street and Inghan Avenue, Trenton, N. J., for a consideration said to be about $150,000. The company will be merged with the parent organization, and raw material including hot rolled strip will be furnished in the future from the Baltimore plant. Plans are under way to increase the capacity of the last noted mill, and 16 new rolling machines with auxiliary equipment will be installed. This will give the Baltimore works an annual output of approximately 20,000 tons. It is also planned to increase the capacity of the Trenton works in the future, and it is expected that certain operations now being carried out at the Baltimore plant will be removed to the new location at Trenton. James Robinson, at one time president of the Keystone Rolling Mill Company, Pittsburgh, Pa., has been appointed general manager of the Trenton plant. Stanton Haines, formerly manager of the Trenton Steel & Wire Company, will be mill superintendent. Rubin S. Baldwin, manager of the Maryland Steel Rolling Company, will have supervision over the Trenton works.

The Brown Steel Company, 480 Neilston Street, Columbus, Ohio, manufacturers of steel products, will soon commence the construction of a new plant addition, adjacent to its present works. The structure will be one-story, 275x305 feet, and equipped for general steel working. It is estimated to cost about $150,000, including equipment. Charles W. Brown is general manager.

Horace T. Potts & Company, 316 North Third Street, Philadelphia, Pa., manufacturers of iron and steel products, will break ground at once for the erection of a new plant on property recently acquired on East Erie Avenue, extending from D to F Streets. The works will comprise a number of one-story buildings, with two main structures, 120x192 feet, and 75x370 feet, respectively, to be equipped with punches, shears, saws and general iron-working machinery, as well as traveling cranes and other handling equipment. The new plant will cost about $500,000.

The Washington Iron Works, Inc., Seattle Boulevard and Norman Street, Seattle, Wash., has plans under way for the construction of a large addition to its plant, to comprise a number of buildings, averaging from 50x100 feet to 130x450 feet, equipped for general iron working. The new plant is estimated to cost in excess of $500,000, and construction will be commenced at an early date. Gerald Fink is president.

The Palmer Steel Company, 316 High Street, Holyoke, Mass., recently organized to manufacture iron and steel products, has awarded a building contract and will commence the immediate erection of the initial unit of its proposed new plant on property lately acquired at Williamsett. It will be about 70x330 feet, equipped for steel fabricating and other work, and is estimated to cost about $75,000. Earl Palmer is president, and Wayne F. Palmer treasurer.

The National Enameling & Stamping Company, 411 Fifth Avenue, New York, N. Y., has plans in progress for the construction of a large addition to its steel mill at Granite City, Ill. The work will consist of six black steel sheet mills, galvanizing sheet mill, and a 72-inch jobbing mill, designed to provide for an additional output of about 5,000 tons of sheet steel per month. The plant will give employment to about 700 additional operatives, and it is expected to cost close to $100,000. George W. Niedringhaus is president.

The Youngstown Steel Company, Youngstown, Ohio, will soon break ground for the construction of a new mechanically operated puddling plant, estimated to cost approximately $1,500,000, including equipment. The new mill will be designed to operate under a special process, whereby considerable mechanical labor will be eliminated. It will give employment to about 200 men. The company also has preliminary plans under consideration for the construction of a new blast furnace with capacity of about 500 tons. The expansion plans provide for extensive increase in operations at the company's works at Warren, Ohio. H. Z. Bixler is company engineer in charge.

The Chapman-Price Steel Company, Shelby Street, Indianapolis, Ind., is having plans prepared for the construction of a large addition to its local mill for extensive increase in capacity. The project will include a number of one-story buildings for different features of steel manufacture, and is estimated to cost approximately $500,000, including machinery. Bids for the work will be called in the near future. Niles Chapman is president.

The Elliott-Blair Steel Company, Taylor and Mercer Streets, New Castle, Pa., has plans in progress for the construction of a new plant to cost approximately $250,000, including equipment. The works will comprise a number of one-story buildings, with installation to include two 12-inch rolling mills, and auxiliary apparatus. A large part of the plant will be given over to the manufacture of cold steel specialties, and all equipment will be electrically operated.

The Tennessee Coal, Iron & Railroad Company, Birmingham, Ala., has plans in progress for the construction of a one-story addition to its plant at Fairfield, Ala. The company is also planning for the remodeling of a portion of its works at Ensley, Ala. The projects are estimated to cost in excess of $100,000.

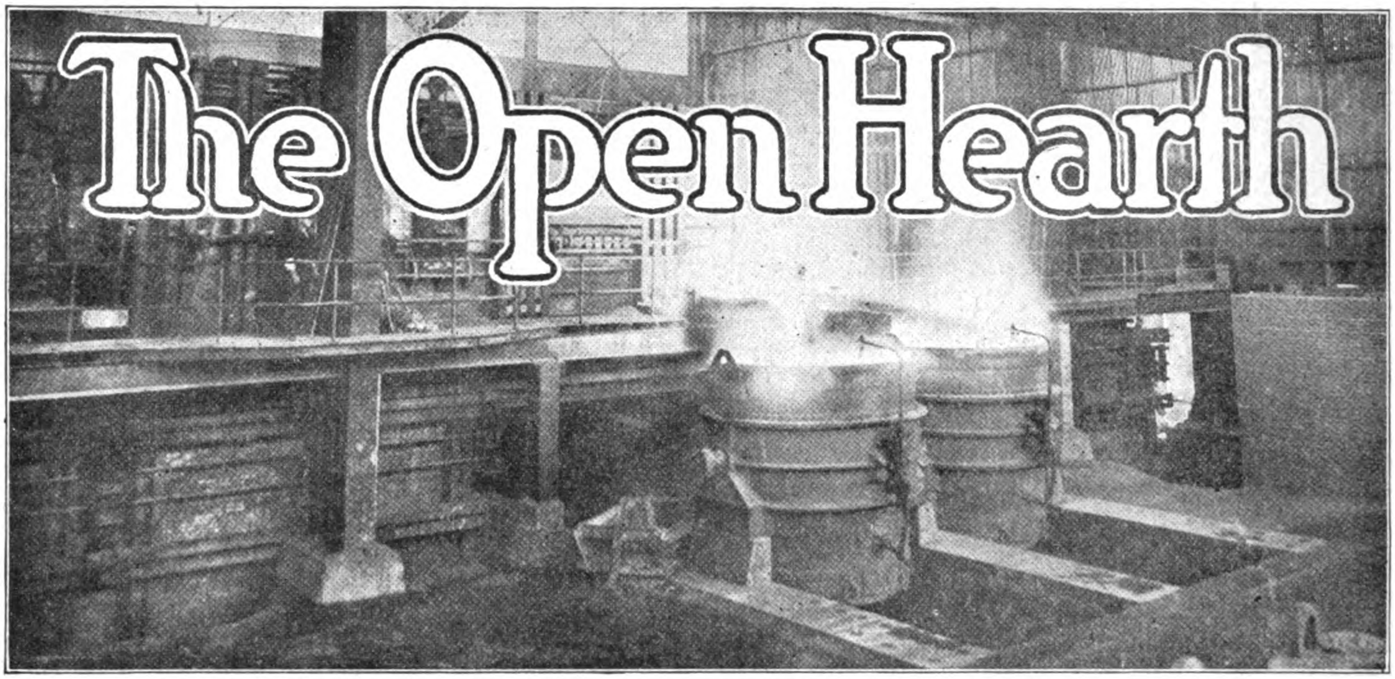
The Herzog Iron Works, East Seventh and Cypress Streets, St. Paul, Minn., has plans under way for the rebuilding of a portion of its plant, recently destroyed by fire, with loss estimated at close to $40,000, including equipment.

The St. Louis Wire & Iron Company, 926-28 Chouteau Street, St. Louis, Mo., has taken bids and will soon break ground for the construction of an addition to its plant for increased production. It will be two-story and basement, 50x140 feet, and is estimated to cost close to $40,000, including machinery. Theodore R. Fiesler is president.

The Penn Seaboard Steel Corporation, Philadelphia, Pa., is arranging for immediate increased operations at the plant of the Carpenter Steel Company, Reading, Pa., recently acquired. The works will be placed on a basis of close to 50 per cent of normal, with further advances expected at an early date.

The Memphis Wire & Iron Works, Memphis, Tenn., has preliminary plans under way for the construction of a one-story addition to its plant on Third Street, for general increase in capacity. It is estimated to cost about $50,000. McLean & Broadwell, Memphis, are architects. W. A. Haglin is president.

The Algoma Steel Company, Sault Ste. Marie, Ontario, has resumed operations of three blast furnaces at its plant, following a curtailment for a number of months. The company has secured a large order for steel rails, and this branch of the works will engage under maximum capacity with full working force.



The Open Hearth

William E. Hoblitzelle, vice president of the Duquesne Steel Foundry Company, Pittsburgh, will become president and general manager of the Smith & Davis Mfg. Company, St. Louis, in which he has acquired controlling interest, on August 15. Mr. Hoblitzelle was formerly general manager of the American Steel Foundries at St. Louis and general manager of the Commonwealth Steel Company, St. Louis. He resigned from the latter connection in 1918.

* *

R. D. Shields has been appointed assistant general manager of the Ohio Machine Tool Company, Kenton, Ohio. Mr. Shields will continue also as chief engineer, which position he formerly held.

* *

Arthur H. Quigley, for 12 years associated with the Kenosha, Wis., works of the American Brass Company, now owned by the Anaconda Copper Company, on July 1 was transferred to Toronto, Canada, as general manager of the Bronze-Brass-Copper Rolling Mills, Ltd., Toronto, an Anaconda interest. Mr. Quigley will have complete charge of development work as well as the general supervision of existing plants. He joined the Coe Brass Company at Torrington, Conn., in 1902 as an office employe, later becoming assistant to the president. In 1910 he was made office manager at Kenosha and in 1917 appointed assistant general manager under Clark S. Judd.

* *

N. R. Seidle was recently appointed works manager for the General Boilers Company, Waukegan, Ill.

* *

C. C. Clark has been named as successor to Kenneth C. Gardner who recently resigned as general sales manager, central district, Pressed Steel Car Company, to become vice president in charge of sales for the Greenville Steel Car Company, Greenville, Pa. Mr. Clark has been affiliated with the Pressed Steel Car Company for 20 years.

* *

Floyd H. Smith, formerly with the Pierce Arrow Motor Company, Buffalo as director of purchases, has become associated with the Simms Magneto Company, East Orange, N. J., as assistant general manager.

Silas H. Horn has become chief engineer for the Johnson Bronze Company, New Castle, Pa. Mr. Horn was formerly with the Brass & Bronze Company, Toledo, Ohio.

* *

Arthur A. Hammerschlag, president of Carnegie Institute of Technology, Pittsburgh, since 1903, has resigned and will become consulting engineer and advisor to corporations, with offices in Pittsburgh and New York.

* *

At a recent meeting of the board of directors of the Consolidated Steel & Iron Corporation, St. Louis, Mo., J. R. Finkelstein, president Hoosier Rolling Mill Company, Terre Haute, Ind., was elected president of the Consolidated Corporation. The other officers follow: F. J. Stuart, chairman of the board; Hugh Ferguson, first vice president; E. J. Schroeder, vice president and treasurer; M. C. Walsh, secretary.

* *

Charles H. McKnight, who has held the positions of president and chairman of the Carbon Steel Company, Pittsburgh, recently resigned from the former office at a meeting of the board of directors. C. F. Blue, Jr., who has been vice president, is Mr. McKnight's successor, and Frank C. Neale, president Kittanning Iron & Steel Mfg. Company, controlled by the Carbon Steel Company, and a director of the latter, has been made vice president in succession to Mr. Blue.

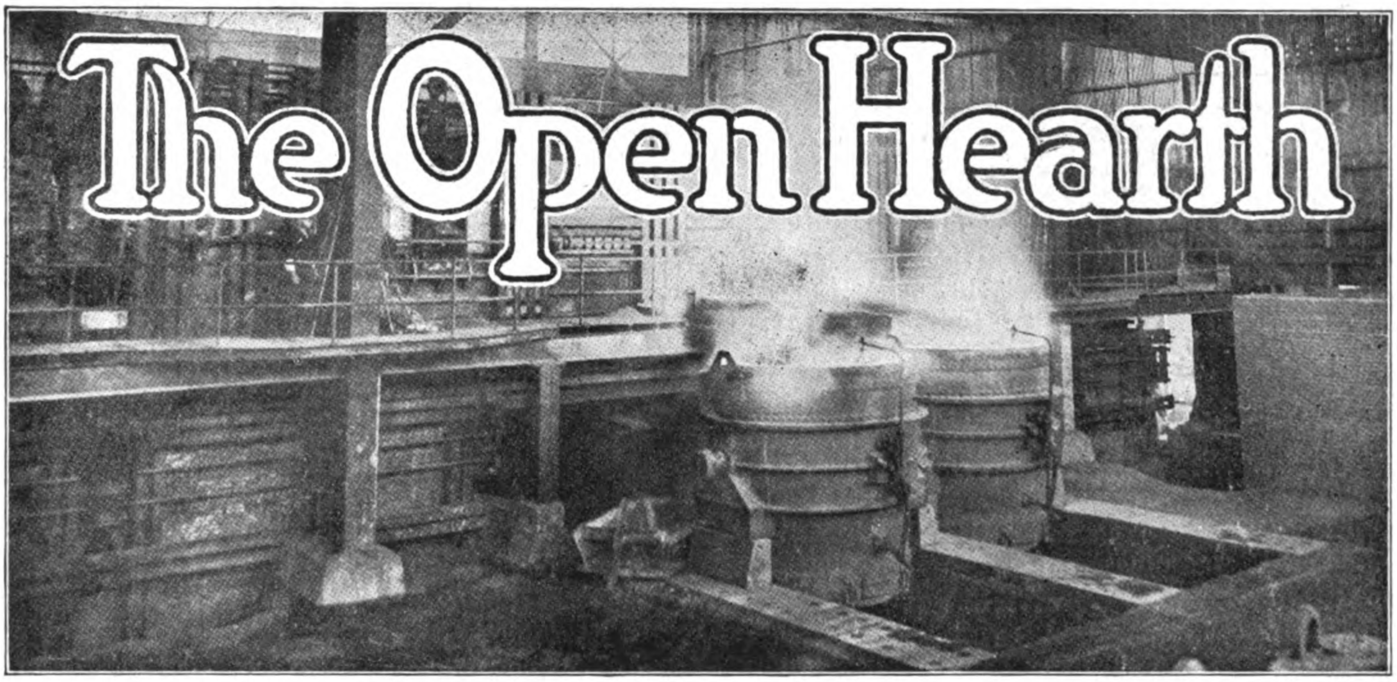
* *

F. G. Peterson, who has been managing superintendent of foundries, Bucyrus Company, South Milwaukee, Wis., for five years, has resigned to accept the position of general superintendent, Hercules Steel Casting Company, Milwaukee, succeeding Frank E. McIntyre, who has returned to the National Brake & Electric Company, Milwaukee. Operations were resumed by the Hercules Company on July 5 with a normal force after being idle for nearly a year.

* *

James A. McCrory has resigned as secretary and general manager of sales for the American Steel Company, Park Bldg., Pittsburgh, Pa., effective July 15. Mr. McCrory plans to engage in business on his own account after a vacation.

The Open Hearth



Edward Peterson has become associated with the Birdsboro Steel Foundry & Machine Company as chief engineer. He was formerly assistant chief engineer of the Treadwell Engineering Company of Easton, Pa., and prior to that was assistant to Mr. A. F. Backlin, chief engineer of the American Steel & Wire Company, Pittsburgh, Pa.

V V

Walter W. Leck resigned June 1 as general superintendent of the American Tube & Stamping Company, Bridgeport, Conn., to become general superintendent of the Scullin Steel Company, St. Louis. Mr. Leck was superintendent of rolling mills at the Steelton, Pa., plant of the Bethlehem Steel Corporation, prior to his connection with the American Tube & Stamping Company.

V V

Bertram D. Quarrie has resigned as general superintendent of blast furnaces and steel works of the American Steel & Wire Company to become general manager of the Otis Steel Company, Cleveland, a new position just created by that company.

V V

W. S. Stothoff, formerly works manager of the Hadfield-Penfield Steel Company, Bucyrus, Ohio, has resigned to engage in other business in the east. Mr. Stothoff is succeeded by R. O. Perrott, secretary of the company and resident manager of the Bucyrus plants, who has become manager of all the plants, the others being located in Mansfield and Willoughby, Ohio. Arthur Whitcraft has become manager of the company's steel foundry in Bucyrus.

V V

Frank L. Estep, junior partner of the firm of C. P Perin & S. M. Marshall, consulting engineers, New York, who recently sailed for Europe. plans to remain a few weeks in England in connection with engineering work for the Tinplate Company of India. Mr. Estep will supervise the completion of construction and the starting up of the plant in India. He will also represent his firm while in India in connection with work being done for the Tate Iron & Steel Company, the Mysore Distillation & Iron Works, the Indian Steel Wire Products Company, the Agricultural Implements Company, Ltd., and other enterprises.

V V

Frederick R. Sites was recently appointed private secretary of Judge Elbert H. Gary, chairman of the United States Steel Corporation, succeeding George K. Leet, who, after serving as private secretary for 11 years, was elected secretary of the Steel Corporation last April. Mr. Sites graduated from the Massachusetts Institute of Technology in 1899 and served for about a year in a minor capacity at the Central blast furnaces of the American Steel & Wire Company, Cleveland, and later in the Metallurgical Department of the Carnegie Steel Company, Homestead, Pa., for about a year. Nine years ago he became associated with the United States Steel Products Company and has just returned from Shanghai, China, where he has been manager in China for that company. During a part of the years 1918-19, Mr. Sites was treasurer of the Federal Shipbuilding Company, but returned to China when the export business became active after the war. Judge Gary became well acquainted with Mr. Sites while making a tour of the Far East six years ago. Mr. Leet, who has been serving as private secretary to Judge Gary, as well as secretary of the Steel Corporation since his election to the latter position, will now devote his entire time to the position of secretary of the Steel Corporation.

V V

S. F. Cox, formerly assistant to the consulting engineer of the Pittsburgh Plate Glass Company, has been made chief engineer of the Calorizing Company, Pittsburgh, the duties of which include management of the Wilkinsburg, Pa., plant of the company.

V V

Earl S. Murton was recently promoted to the position of assistant superintendent of the sheet department, Inland Steel Company, Indiana Harbor, Ind. Mr. Murton was formerly hot mill foreman of the plant. Prior to going to the Inland Company, Mr. Murton was with the Canton Sheet Steel Company, Canton, Ohio.

V V

James H. Walsh, who, for twenty years, was superintendent of the rolling department, South Chicago Works, Illinois Steel Company, has resigned to become assistant general superintendent of the Inland Steel Company, Indiana Harbor, Ind.

V V

Commander A. J. Chantry, Jr., U. S. N., has reported to the Charlestown Navy Yard, Boston, as production manager. He succeeds Commander W. B. Fogarty, who has been assigned to duty at Groton, Conn., as superintendent Electric Boat Company. Commander Chantry formerly was attached to the Philadelphia Navy Yard.

WITH THE EQUIPMENT MANUFACTURERS

"LITTLE GIANT" PIPE WRENCH PRESENTED TO THE TRADE

The "Little Giant" Pipe wrench, a new wrench with several interesting improvements has just been put on the market. The wrench has the "end opening" feature which is familia rto users of machinists' wrenches. Its application to pipe turning can readily be seen by a blance at Fig. 1.

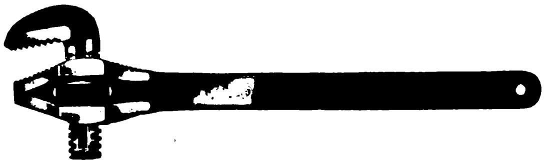


Fig. 1.

The advantage of the "Little Giant" wrench over the conventional style is the ease with which it can handle pipes in corners, close to walls, and similar confined places. The person using it can set it straight on the pipe as he would a pair of pliers, instead of having to fit the jaws on from the side.

The wrench has only three parts; a handle and jaw in one piece, which is drop forged and heat treated; a movable jaw, likewise drop forged and heat treated and a hardened steel nut. There are no springs, rivets, frame or pins, all these parts being eliminated. In spite of the absence of springs it takes hold and releases instantly at the option of the user.

The new wrench has been designed for maximum strength. The 14 in. size has repeatedly withstood stresses in excess of 4,700 inch pounds without slipping or bending. Readers familiar with government requirements will recall that the army and navy departments require a test of 2,800 inch pounds for a wrench of this size. Yet owing to the elimination of extra parts the "Little Giant," in spite of its extra strength weighs less than a Stillson type wrench of corresponding capacity. This is an advantage to users and dealers alike.

Another feature is the double set of teeth on the main jaw. The movable jaw can be engaged at the option of the operator with either of these sets of teeth with consequent lengthened life. On the large sizes, 14 in. and greater, two additional sets of teeth are provided, making four in all, and the movable jaw can be reversed to engage these additional sets of teeth, which are below the adjusting nut. This is very useful in connection with certain classes of work, besides practically quadrupling the life of the tool.

The new wrench is a product of the Greenfield Tap & Die Corporation, Greenfield, Mass. "Little Giant" is one of their trade marks, well known throughout the trade to all users of Screw Plates, Taps and Dies.

VAN DORN BUILDS A SPECIAL RADIAL ARM DRILL FOR MILLWRIGHT WORK

Realizing the great need in the industries for suitable tools especially adapted to the peculiar needs of millwrights and maintenance men, the Van Dorn Electric Tool Company of Cleveland, Ohio, has introduced the "Millwright Special," a Millwright's Radial Arm Drill to be attached to the wall or column for performing various jobs of a heavier stationary nature where rigidity and greater accuracy may be required.

Knowing the hard use and abuse to which portable electric tools are often subjected, the Millwright Drill is built strong and rugged in every part, completely encased in an aluminum housing also arranged for quick dissembling for greasing and cleaning.

The entire drill is well balanced, also very light and convenient to handle so that the operator can easily use it in most any position without experiencing extra exertion or fatigue.

The motor is of the universal type, for either A.C. or D.C. circuits. It is of the usual powerful and durable "Van Dorn" construction throughout, properly ventilated by an aluminum fan on the rotor shaft, and ball bearing equipped.

A special drill chuck permits the use of drills up to ⅝ in. diameter for drilling holes in iron and steel, while much larger wood bits can also be used.

The Millwright Radial Arm is of unique design with proper distribution of metal to give great strength and rigidity to withstand the heaviest drilling requirements, at the same time keeping the weight within limits that permit an easy swinging motion of the arm to allow quick location of the drill when in service; besides its convenient weight, permits the radial arm to be moved from one location to another when its services are required in different parts of the factory.

Two large pivot brackets bolted to the wall or column, support the entire arm. At the opposite end of the main arm casting is a second joint on which the short fore-arm swings. The outer bearings of the fore-arm form a support and guide for the drill bracket column. This forearm or second joint member gives great flexibility which permits accurate location of the drill.

The drill bracket or sliding member is raised and lowered by means of a long lever and toggle link mechanism. A secondary drill lifting arrangement is also provided in the form of a strong tension spring attached to the lower part of the drill bracket and hung from an extension rod above the fore-arm.

The Millwright Drill can be quickly attached to the Radial Arm by simply unscrewing one handle and bolting the drill to the adapter plate on the radial arm. Less than one minute is required to attach the drill from the arm.

The entire scope of the arm with the drill attached covers a radius of 31½ inches from the drill center to wall pivots. The auxiliary forearm permits a secondary radius of 10½ inches to be swung for locating the drill.

The British Empire Steel Corporation, Montreal, Que., has preliminary plans under way for extensions and improvements in its plant, to cost in excess of $15,000,000. Plans are being prepared for new open hearth furnaces and new blooming mill, estimated to cost about $10,000,000. Extensive improvements will be made to two blast furnaces, including relining and general repairs. Other portions of the mill will be remodel and new machinery installed, bringing up the expenditure to about the point noted.

Some Pointers on By-Product Coke Oven Operations

THE RECOVERY OF BENZINE BY MEANS OF CHARCOAL

Several papers have been written during the last year on the Bayer process of recovering solvents like benzine, carbon disulphide, ethylene, etc., from solutions used in various important industries, as well as from coke oven gas, by means of "activated" charcoal. The Bayer Farbenfabriken of Leverkusen are activating charcoal by carbonizing wood in the presence of zinc chloride and other salts at 1,000 deg. C., and they claim thus to obtain a charcoal which, as regards benzine, is 20 times as active as ordinary charcoal. The regeneration of the charcoal is effected by means of dry steam at 180 deg. C. In the laboratory the Bayer method is already used to a considerable extent. Coke-oven works wash the gas with some oil to strip it of its benzine, and the technical substitution of activated charcoal for oil is so far only being tried. The two processes, washing with oil and adsorption by charcoal, are entirely different. The former process relies upon the solubility of benzine in the oil, the second on surface adsorption.

DESULPHURIZING OF COKE

A study of the desulphurization of coke was begun July 1 at the experiment station of the United States Bureau of Mines at Pittsburgh. This is a practical follow-up of the theoretical study of the oxidation of iron sulphate in the coke and subsequent removal of the free sulphur formed by this oxidation. Literature on this subject is being reviewed. Many patents were taken out in the years 1850 to 1870 and few since. Roasting and steaming were favorite methods. In this connection, methods for converting sulphur in coke into the FeS form are being sought. A process based on such method would hold back sulphur that might ordinarily be evolved, then this sulphur could later be removed by oxidation together with much additional sulphur. It seems that Fe_3O_4 mixed with coal being coked decreases the sulphur in solid solution. The work is being undertaken by Dr. A. R. Powell, physical organic chemist, and John H. Thompson, research fellow of the Carnegie Institute of Technology.

NEW RECORD IS MADE IN BY-PRODUCT COKE

To replace the deficit in beehive coke caused by the strike in the Connellsville region and other beehive coke districts, the by-product ovens are now producing at a rate above the average for 1920. The Geological Survey reports the total output of by-product coke in June was in round numbers 2,580,000 net tons, against a monthly average of 2,565,000 tons in 1920, the record year. The average output per working day was 86,000 net tons, an increase of 5 per cent over the May average. The month's production represented 70 per cent of the aggregate capacity of the ovens. Of the 71 plants in existence, 58 were active and 13 idle.

Because of the low production of beehive coke, 458,000 tons in June, against a monthly average of 1,748,000 tons in 1920, the total output of all coke was only 3,038,000 tons. This was 70.5 per cent of the monthly average of all coke in 1920.

COKE INVESTIGATIONS AT BIRMINGHAM

Investigations now being conducted by the Bureau of Mines at the Southern experiment station, Birmingham-Tuscaloosa, Ala., cover the physical properties of blast furnace coke, including physical tests, solubility of coke in carbon dioxide, and analyses of blast furnace hearth gas. In the study of the reactivity of coke with carbon dioxide, the effect of mesh of coke, temperature, rate of flow of carbon dioxide, and dilution with nitrogen has been further investigated. The work on hearth gas analyses at the plants of the Republic Company and the Tennessee Coal, Iron & Railroad Company has been completed. Completion of work at the plant of the Alabama Company at Gadsden, Ala., makes a total of six furnaces investigated in the Southern district.

SPECIFIC GRAVITY OF COKE

Experimental work is being conducted at the Pittsburgh, Pa., experiment station of the Bureau of Mines on the influence of fineness, medium, and time of boiling, in determining the true specific gravity of coke, which determination is used in calculating the amount of cell space or porosity of metallurgical coke.

MIXED COAL AND COKE FUEL FOR WATER GAS MANUFACTURE

Results obtained by W. J. Dunkley, gas engineer of the Bureau of Mines, in the course of experiments made at Ottawa, Ill., in the use of mixed coal and coke fuel for water gas manufacture, show that capacities up to 97 per cent of the rated capacity with good coke fuel can be obtained, using 70 per cent Illinois coal and 30 per cent coke from Kentucky coal, with 6 ft. gas sets operating up to 10 hours per day. The generator fuel consumption was about 33.5 pounds of mixed fuel per 1,000 cubic feet of gas made.

CARBONIZED LIGNITE FUEL

Experiments on the treatment of lignite, raw and carbonized, by the Trent process, are being made in North Dakota by W. W. Odell, fuel engineer of the United States Bureau of Mines. Construction of a vertical lignite carbonizing oven has been completed.

CARNEGIE TECH TO TEACH METALLURGY TO NAVAL OFFICERS

Carnegie Institute of Technology at Pittsburgh has been selected by the United States Naval Academy at Annapolis to give advanced courses in metallurgy to its graduate officers. Beginning next September, the Naval Academy will send two ordnance officers, graduates of the Acamedy, for a year's study in advanced metallurgy. Their studies will be confined principally to advanced metallurgy but will include some studies in electricity and physical chemistry. Other groups of graduate officers are assigned each year to various colleges or universities to study along specialized lines.

F. F. McIntosh, associate professor in metallurgy at Carnegie Tech, will supervise the studies of the naval officers. Lieutenants Gilbert C. Hoover and John H. Keefe have been assigned to take the work the next college year.

STUDYING STEEL SUITABLE FOR GAGES

Experimental work has been started by the Bureau of Standards in the study of the rate of or resistance to wear of steels when run in contact and without lubrication of any sort. The Amsler wear testing machine is being used for this investigation. The steels included in the preliminary studies form a series that has been submitted by the gage steel committee and which is being studied in detail to determine the suitability of the steels for gages. In gage work, the question of wear is of extreme importance.

TRADE NOTES

The Mesta Machine Company, Pittsburgh, Pa., announces the removal of their Chicago office from the McCormick Building to the Peoples Gas Building. Mr. C. J. Mesta, second vice president of the company, who has been in charge of the Chicago office for over a year, has returned to the home office in Pittsburgh to take charge of the sales department of the company. Mr. A. B. Neumann, mechanical engineer, has been appointed manager of the Chicago office. Mr. Neumann has been in the Chicago district for a number of years in the capacity of chief engineer and consulting engineer for several of the largest steel plants in that district.

Two large foreign contracts have just been closed by the Electric Furnace Company, Salem, Ohio. The first calls for an aluminum melting furnace for Germany, and the second for a set of automatic heat treating units for Japan. The United Aluminum Works, Lautewerke, Germany, has contracted for a 200-kw. tapping type electric furnace capable of holding 4,000 lbs. of aluminum. Mitsui & Company, New York City, has purchased, for shipment to Japan, a completely automatic set for heat treating forgings. The hardening furnace will be rated at 80 kw. and will contain five rows along which the forgings will advance.

The Economy Fuse & Mfg. Company of Chicago, Ill., announces the appointment of Charles H. Bluske as district sales manager of the Los Angeles office at 1304 Maltman Avenue.

The Pittsburgh sales office of the Economy Fuse & Mfg. Company has been moved from 2223 Farmers Bank Building to 1006 Peoples Bank Building at Fourth Avenue and Wood Street.

C. F. Ford, who for the past several years has been with the Chicago Pulley & Shafting Company, has recently joined the engineering sales forces of W. A. Jones Foundry & Machine Company, manufacturers of speed reducers and power transmitting machinery. In the near future Mr. Ford will be located in Minneapolis as manager of the Jones branch there.

The New Orleans Gas Light Company will install two U. G. I. vertical waste heat boilers and to that end have awarded contract for the installation to the U. G. I. Contracting Company of Philadelphia. These waste heat boilers will be attached to the carburetted water gas apparatus.

The Younglove Construction Company, United Bank Bldg., Sioux City, Ia., has been appointed representative of the Conveyors Corporation of America, 326 West Madison Street, Chicago, Ill., for the sale of American trolley carriers in northwestern Iowa and in South Dakota.

The Electric Furnace Construction Company, 908 Chestnut Street, Philadelphia, manufacturers of electric furnaces, "Electro" steam boilers, etc., report an increase in capital and the appointment of the following new officers: P. H. Falter, vice president and treasurer; Arthur G. Dickson, of Beitler & McCouch, Philadelphia, vice president and counsel; and of the following new directors: John Gilbert of Madeira, Hill & Company; Wm. A. Webb, president Empire Coal Mining Company; Dr. T. H. Weisenburg. Frank Hodson retains the presidency of the company.

The Torrington, Conn., Electric Company is making improvements to its gas plant in order to provide for increased manufacturing capacity and has placed its orders with the U. G. I. Contracting Company of Philadelphia.

The Iron & Steel Products Company has removed from 230 Fifth Avenue to 421 Wood Street, Pittsburgh, Pa. The company handles iron and steel products, specializing in relaying rails; also copper and brass, babbitt and solder, brake lining and packing.

TRADE PUBLICATIONS

The Hydraulic Society has gotten out a second edition of its pamphlet entitled "Trade Standards in the Pump Industry." This edition contains some additional tables and explanatory data, and also a revised list of members of the society. Copies may be secured from the members or the secretary, C. H. Rohrbach, 50 Church Street, New York, and if desired in quantities, will be supplied at cost of printing.

The Brown Instrument Company of Philadelphia, Pa., announce the publication of a new resistance thermometer catalog which explains the theory of resistance thermometry, the various types of instruments which are made, and the merits of each type, suggesting the really wonderful field which this instrument so ideally covers.

The American Engineering Company of Philadelphia has just issued a new publication entitled "The Rotary Ash Discharge." This booklet deals exclusively with a system of ash treatment and discharge which was originated and perfected by that company.

The Uehling Instrument Company of Paterson, N. J., have issued their four-page bulletin No. 113 describing their Pyro-porus filter for filtering flue gas samples to exclude soot and dirt.

The George T. Ladd Company of Pittsburgh, Pa., have issued a four-page folder, entitled "The World's Largest Power Boilers After Eighteen Months Operation." In it they tell of the performance records secured with their boilers at the River Rouge plant of the Ford Motor Company and reproduce four interesting steam flow charts. The boilers have operated for periods of four to seven months, each normally carrying 200 to 250 per cent rating, and at times for periods of 16 to 20 hours 300 to 350 per cent. At one time a rating as high as 425 per cent was reached. The last page of the pamphlet is devoted to a list of advantages of Ladd water tube boilers. Size 8½x11.

"Regulating Boiler Feed Water" is the title of a booklet just published by the Northern Equipment of Erie, Pa. It is divided into three general sections. The first is a reprint of an article from Power Plant Engineering emphasizing the importance of feed water regulation and discussing the requirements to be met. The second describes and illustrates the regulator made by this company. The third consists mainly of charts and descriptions of them showing how this regulator has met the requirements enumerated. Size 8¼x11. Twenty pages bound in heavy craft cover.

"Koerting Fuel Oil Burning Systems," is the title of a new catalog consisting of three bulletins bound in a stiff cover, recently issued by Schuette & Koerting Company, Philadelphia, Pa. The bulletins bear the titles, Mechanical Fuel Oil Burning Systems, Low and High Pressure Fuel Oil Burners, and Properties and Advantages of Fuel Oil. In them are discussed installations, operation and maintenance of oil burning equipment, the relative merit of mechanical spray oil burners, oil pumping outfits, the general requirements of steam boiler furnaces for burning oil, air for combustion, effects of carbon deposits and soot, etc. Size 8¼x11¼.

The London Steam Turbine Company of Troy, N. Y., successors to the Steam Motors Company, have issued their Bulletin No. 14 under date of May, 1922. In it they describe the advantages and features of their product. The bulletin is well printed on coated stock and contains a large number of excellent illustrations. Twenty-eight pages, size 8½x11.

Westinghouse Electric & Mfg. Co., East Pittsburgh. Circular 1579-B, containing general and technical data on Micarta, a non-metallic material for gear and pinion application, developed by the Westinghouse company. It is a laminated product of specially treated woven fabric of homogeneous structure and physical properties are claimed for it that make possible its substitution for untreated steel, cast iron, bronze and other materials used in gear manufacture. It is self-sustaining and may be machined with ordinary standard tools and equipment.

American Nickel Corporation, Clearfield, Pa. A 12-page bulletin, 8½ in. x 11 in., giving a resume of the properties and uses of pure nickel, shown by graphs and tabular comparisons.

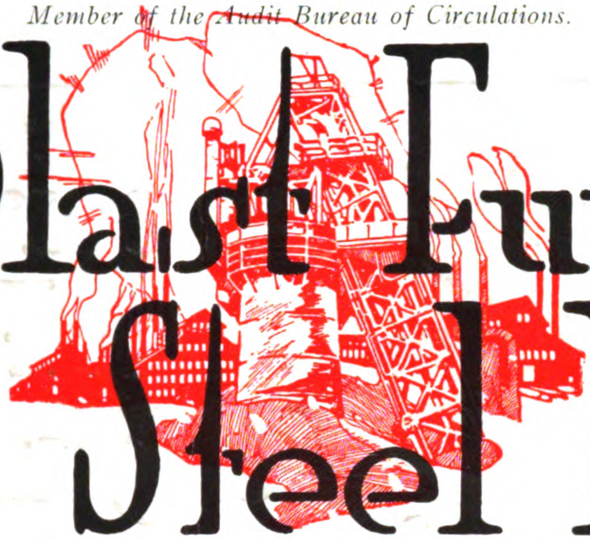
66

Member of the Audit Bureau of Circulations.

Entered as second class mail matter at Pittsburgh, Pa., under the Act of Congress, March 3, 1879.

THE JOHN CRERAR LIBRARY
AUG 11 1922

The Blast Furnace and Steel Plant



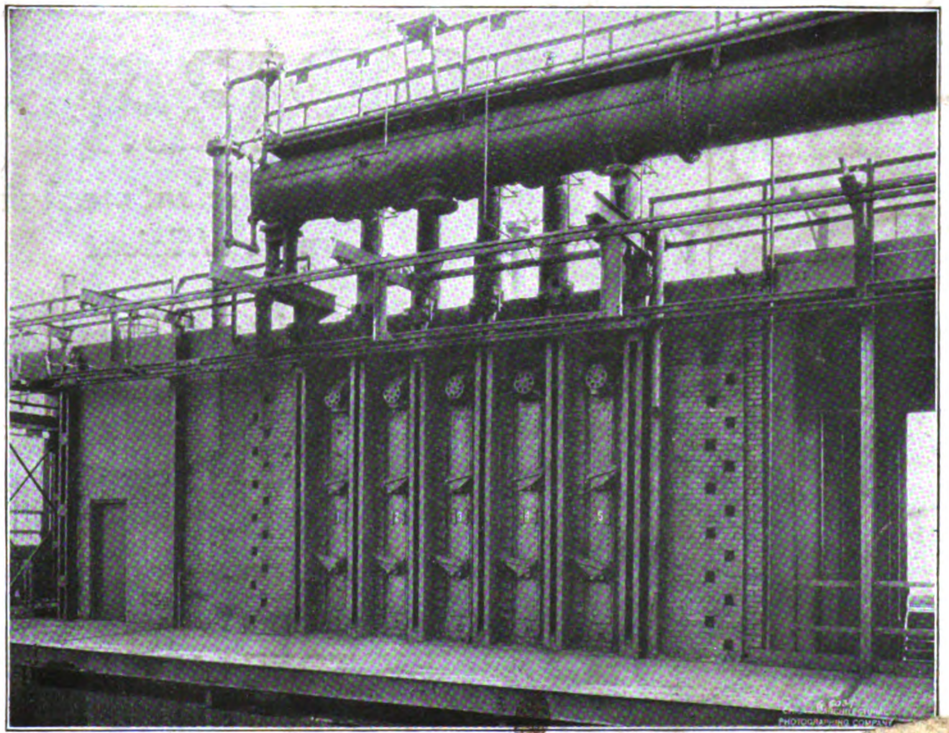
Pittsburgh, August, 1922.

Koppers By-Product Coke Ovens

For fifteen years The Koppers Company has had the enviable reputation of designing and building the best in by-product coke ovens.

The performance of the more than 7,000 Koppers Ovens in operation or under construction in the United States and Canada is the best proof that it is entitled to this reputation.

In recommending the NEW KOPPERS OVEN, it is with the firm conviction, backed by actual operating results, that in this oven we have reached a degree of perfection which far excels all previous accomplishment and gives a new conception of by-product coke oven efficiency.



Battery of five NEW KOPPERS OVENS at Chicago
By-Product Coke C [illegible]

THE KOPPERS COMPANY
PITTSBURGH